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The Consistent Association Between Epstein-Barr Virus and Hodgkin's Disease in Children in Kenya

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Recent studies have suggested that Epstein-Barr virus (EBV) may play a role in the etiology of Hodgkin's disease (HD). In a previous study, we used latent membrane protein 1 (LMP1)-specific antibodies to examine archival material from 74 British children with HD and found 50% of cases to be positive. It is known that there are geographic and ethnic variations in the incidence of HD. We have investigated LMP1 status in formalin-fixed, paraffin wax-embedded lymph nodes with HD involvement from 53 children and 48 adults from Kenya using immunohistochemical staining. We also developed sensitive and specific in vitro gene amplification protocols for examining the EBV strain type in such material using several combinations of primers derived from the EBNA 2 and EBNA 3 coding regions. LMP1 positivity was present in 100% of the pediatric cases (two lymphocyte-predominant, 25 nodular sclerosis, 16 mixed cellularity, 5 lymphocyte depletion, and 5 unclassified) and in 66% of the adult cases (two of three lymphocyte-predominant, 26 of 39 nodular, sclerosis, two of two mixed cellularity, and two of four lymphocyte depletion). Tests to type the EBV strain were undertaken in 25 EBV-positive pediatric cases. A combination of type-specific polymerase chain reactions for EBNA 2 and EBNA 3C genes indicated that seven patients had type 1, eight had type 2, and 10 had dual infections with both types. Five cases with dual infections were further investigated using a sensitive in situ hybridization for the EBV-encoded, small nuclear nonpolyadenylated RNAs (EBERs). EBER transcripts were detected in Reed-Sternberg and Hodgkin cells and in occasional infiltrating lymphocytes. These observations indicate that in Kenya EBV is consistently associated with pediatric cases of HD, and that biopsies from a number of such cases appear to carry both type 1 and type 2 viral sequences.

EPSTEIN-BARR VIRUS (EBV) is ubiquitous and has been found as an asymptomatic infection in all human communities.[1] However, geographic and ethnic variation have been recognized by studies of the incidence of EBV-associated malignancies, namely, Burkitt's lymphoma and nasopharyngeal carcinoma.[2,3] In addition, an association between EBV and Hodgkin's disease (HD) is now supported by a variety of evidence.[4,5] Thus, serologic and epidemiologic studies in adults first raised the possibility of an association between EBV and HD,[6,7] followed by molecular detection of EBV in HD biopsies. In this context, Southern blotting and the polymerase chain reaction (PCR) are specific and sensitive methods for detecting EBV genomes, but do not determine which cell population in the biopsy is infected by the virus.[8-12] This contrasts with in situ hybridization, where viral sequences have been demonstrated selectively in malignant cells.[13] Further evidence for an active role of EBV in the pathogenesis of HD was provided by reports that EBV-positive malignant cells express the virus latent membrane protein 1 (LMP1), one of the key effectors of EBV-induced cell transformation in vitro.[14,16]

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In a previous study we used LMP1-specific monoclonal antibodies to examine archival material from 74 British children with HD. LMP1 was clearly expressed in malignant cells in 50% of the cases.[17] Here, the association between EBV and HD tended to be more frequent in patients presenting with advanced-stage disease, but individual examples of LMP1-positive tumors could be found among all histological subtypes and at all stages of the disease.

EBV strains can be classified into two main types, type 1 and type 2, based on the polymorphism within the gene loci encoding EBNA 2, 3A, 3B, and 3C proteins.[18,19] These proteins, which are consistently expressed in EBV-transformed B cells, contribute to the biological differences between type 1 and type 2 viruses. These are most evident in the reduced transformation capacity of the type 2 virus, making the production of type 2 EBV cell lines difficult.[20] Initial results suggested that type 2 strains were found predominantly in central Africa and New Guinea,[21] whereas type 1 strains were more common in Western countries.[22]

As part of our studies to determine whether the association of EBV with HD shows geographical variation, immunohistochemical staining for LMP1 was used to screen HD cases arising in a Kenyan population consisting of both children and adults. We have also established sensitive PCR methods for detection and typing of EBV in lymph nodes with HD involvement. Five cases were further investigated using a sensitive in situ hybridization technique for the EBV-encoded, small nuclear nonpolyadenylated RNAs (EBERs), which are present at levels of 10^7 copies per cell in latently infected cells.[23]

PATIENTS AND METHODS

We studied archival biopsy material from 101 Kenyan patients: 53 pediatric cases (aged < 16 years) and 48 adult cases diagnosed with HD in Kenyatta National Hospital in Nairobi between 1981 and 1991. Each biopsy was reviewed by three independent histopathologists (A.N., F.R., and M.W.) and subclassified in accordance with the Rye convention.[24]

Immunohistochemical staining. Formalin-fixed, paraffin wax-

Table 1. Cell Lines of Burkitt's Lymphoma Origin or Lymphoblastoid Cell Lines Generated by In Vitro Transformation of Normal B Cells With Different EBV Isolates

	EBV-Positive	
EBV-Negative	Type 1	Type 2
BL 2	KYU-BL	CHEP-BL
BL 30	WW-1-BL	WW-2-BL
BL 40	MUTU-BL	GOR-BL
BJAB	ODHI-BL	WAN-BL
MOLT 4	B 95.8-LCL	ELI-BL
Ramos	[CR + BL 37] LCL	AG 876
	[C2 + OBA] LCL	JC5-LCL
	Zost-1-LCL	[C2 + BL 16] LCL
	X 50-7-LCL	
	IB4-LCL	

Abbreviations: BL, Burkitt's lymphoma; LCL, lymphoblastoid cell lines.

Table 3. Histopathologic Subtypes and LMP1 Status in HD in Patients from Kenya

HD	LMP1-Positive	LMP1-Negative	% LMP1-Positive
Childhood			
LP	2	0	100
NS	25	0	100
MC	16	0	100
LD	5	0	100
UN	5	0	100
Total	53	0	100
Adulthood			
LP	2	1	66
NS	26	13	66
MC	2	0	100
LD	2	2	50
Total	32	16	66

Abbreviations: LP, lymphocyte-predominant; NS, nodular sclerosis; MC, mixed cellularity; LD, lymphocyte depletion; UN, unclassified.

embedded sections from each biopsy were stained with a pool of four mouse monoclonal antibodies (CS 1 to 4) specific for LMP1.[25] Staining was developed by double-layer alkaline phosphatase/anti-alkaline phosphatase. We used the method originally developed by Murray et al.[26] EBV-containing lymphoblastoid tumors from SCID mice and known formalin-fixed tissue from EBV-associated cases of childhood HD of non-African origin were used as positive controls. As negative controls, we used archival lymph node biopsies from children with benign lymphoid hyperplasia. Consecutive sections from children's HD biopsies were stained with antibodies against CD30 and CD15 using reagents from DAKO (Glostrup, Denmark).

DNA preparation. DNA from cell lines of Burkitt's lymphoma origin or from an in vitro-transformed lymphoblastoid cell line (LCL) was extracted using a standard protocol.[27] These were used as EBV-negative or EBV type 1-positive or type 2-positive controls (Table 1). For sensitivity testing, we prepared 10-fold serial dilutions (10^3 to 10^6 cells) of EBV-positive cells in an excess of 10^7 EBV-negative cells, of EBV type 1-positive cells in an excess of type 2-positive cells, and of EBV type 2-positive cells in an excess of type 1-positive cells. DNA samples prepared from these mixtures were used as additional standards.

DNA was extracted from formalin-fixed, paraffin wax-embedded tissue using a method previously described.[28]

Oligonucleotide primers. The strain type of EBV was determined using differential PCR. Three pairs of oligonucleotide primers were used to amplify sequences from strain type 1 and type 2, respectively. Common oligonucleotide primers directed against the polymorphic gene sequence of EBNA 3C[19] detected both type 1 and type 2. To verify specificity of the sequence of amplified EBNA 3C fragments, two unique cutting restriction enzymes were identified: *Rsa* I for strain type 1 and *Hpa* II for strain type 2. Two pairs of primers were targeted to the different regions of EBNA 2 type 2 (2B1, 2B2, 2B3, and 2B4).[29] EBNA 2 PCR products were confirmed to be EBV type 2-specific using the presence of a diagnostic *Mnl* I restriction site. Details are shown in Table 2.

PCR. Each amplification reaction was performed in a final volume of 50 μL containing 0.05 μg DNA extracted from formalin-fixed, paraffin-embedded samples or from cell lines, 200 μmol/L of each dNTP, 1 μmol/L of each oligonucleotide primer, 3 U Taq polymerase (Amplitaq; Perkin Elmer, Branchburg, NJ), and the appropriate volume of PCR buffer (Gene Amp; Perkin Elmer). The samples were denatured for 7 minutes at 94°C and subjected to 45 cycles of amplification in a DNA thermal cycler (GeneAmp PCR System 9600; Perkin Elmer). For EBNA 3C primers, one cycle consisted of denaturation for 30 seconds at 94°C, reannealing for 90 seconds at 50°C, and primer extension for 2 minutes at 70°C. For EBNA 2 primers, one cycle consisted of 1 minute at 94°C, 2 minutes at 55°C, and 30 seconds at 72°C.

In situ hybridization. Section from formalin-fixed, paraffin-em-

Table 2. Sequence of Oligonucleotide Primers Used for Type-Specific PCRs and Restriction Sites for Specific Restriction Enzymes

Gene			Sequence 5′-3′
EBNA 3C	Common	5′ primer	5′ GGCTCGTTTTTGACGTCGGC 3′
	Common	3′ primer	5′ AGAAGGGGAGCGTGTTGT 3′
	Type 1	Product	153 bp
	Rsa I	Site	5′ AGAAGGGGAGCGTGTGTTGTGT/ACGACGATGATGATGTCATAGAGGTGATTGAATG 3′
	Type 2	Product	246 bp
	Hpa II	Site	5′ ACCGCCCCCCCCCGTGATTTCTACC/CGGAGTGCCAATGCTTCCAGTCACCGGGAT 3′
EBNA 2	2B.1	Type	5′ TTGCTGAAGGTGTCACTCT 3′
	2B.2	2	5′ GCTGCCCACCCTGAGGATTT 3′
	Type 2	Product	119 bp
	Mnl I	Site	5′ TACTCTTCCTCAACCCAG/AA
EBNA 2	2B.3	Type	5′ GCTGCCCACCCTGAGGATTT 3′
	2B.4	2	5′ GCAGCCCTAAAGCAGACCTA 3′
	Type 2	Product	180 bp

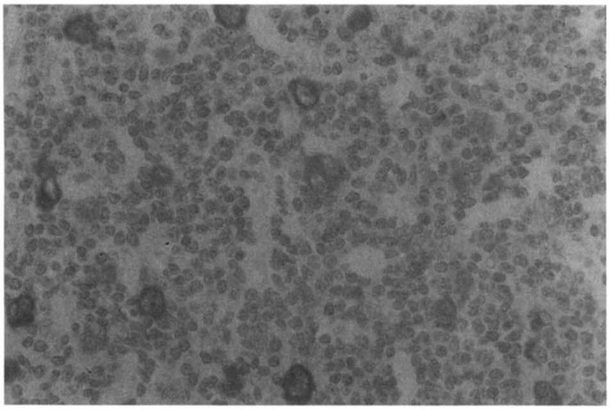

Fig 1. Immunohistochemical analysis of paraffin-embedded section from lymph node with HD LMP1 positivity in Reed-Sternberg and Hodgkin malignant cells. (CS 1 to 4 antibodies: APAAP technique, counterstained with hematoxylin. Original magnification × 250.)

bedded archival HD lymph nodes from children were hybridized with a biotinylated and digoxigenin-labeled probe complementary to EBER 1 + 2. The basis of our method has been reported previously.[30] The hybridization signal was detected with alkaline phosphatase/4-Nitro blue tetrazolium chloride (NBT) 5-Bromo-4-chloro-3-indoyl-phosphate (BCIP) according to Boehringer (Mannheim, Germany). The sense probes to EBER 1 + 2 served as a control for nonspecific hybridization; these were negative in all cases.

RESULTS

LMP1 staining. Of 101 Kenyan HD specimens examined, all 53 pediatric cases were found to be LMP1-positive by monoclonal antibody staining (Table 3), with clear signals over the majority of the malignant cells. A typical example is shown in Fig 1. The histological subtypes of these pediatric cases were lymphocyte-predominant (n = 2), nodular sclerosis (n = 25), mixed cellularity (n = 16), lymphocyte depletion (n = 5), and unclassified (n = 5). However, only 32 of 48 adult cases were LMP1-positive: two of three lymphocyte-predominant, 26 of 39 nodular sclerosis, two of two mixed cellularity, and two of four lymphocyte depletion.

EBV strain types. We then sought to classify the EBV strain type involved in these cases. To optimize the PCR typing protocol, EBV-negative, EBV type 1-positive, and EBV type 2-positive cell lines provided control DNA preparations; in addition, DNA was made from known mixtures of these cell lines. An amplification with EBNA 3C primers resulted in the expected 153-bp fragment for type 1 and 246-bp fragment for type 2. The type 1 EBNA 3C detection was very efficient, with the ability to detect as few as 10^3 type 1 cells either in 10^7 type 2 cells or in 10^7 EBV-negative cells (data not shown). However, insufficient sensitivity for type 2 diagnosis was noted, despite our extensive variation of the reaction parameters. Thus, the type 2 detection limit using EBNA 3C primers exceeded 10^5 type 2 cells in 10^7 type 1 cells (an effect possibly due to the mutual competition between EBNA 3C primers) and was approximately 10^4 type 2 cells in 10^7 negative cells (data not shown). We examined type 1 and type 2 products using diagnostic restriction enzyme sites identified from the prototype B 95.6 (type 1) and Ag 876 (type 2) sequences. The enzyme *Rsa* I recognized a specific restriction site in type 1 sequences amplified from all four lines tested (Fig 2), but in only one of four type 2 lines tested (JC 5; Fig 2). Conversely, the enzyme *Hpa* II recognized a specific restriction site in all four type 2 lines tested, but not in any type 1 lines (Fig 2).

PCR analysis was extended to provide a more sensitive assay for type 2 viral strains based on amplification of regions of the EBNA 2 gene. Two different primer combinations were used (2B1/2B2 and 2B3/2B4), and both combinations detected type 2-positive cells as low as 10^3 cells in a background of 10^7 type 1-positive cells or 10^7 EBV-negative cells (Fig 3). The specific restriction enzyme *Mnl* I was used as a diagnostic test for PCR-amplified product of the 2B1/2B2 primer combination, and all EBV type 2 cell lines tested produced a digestion pattern (Fig 4).

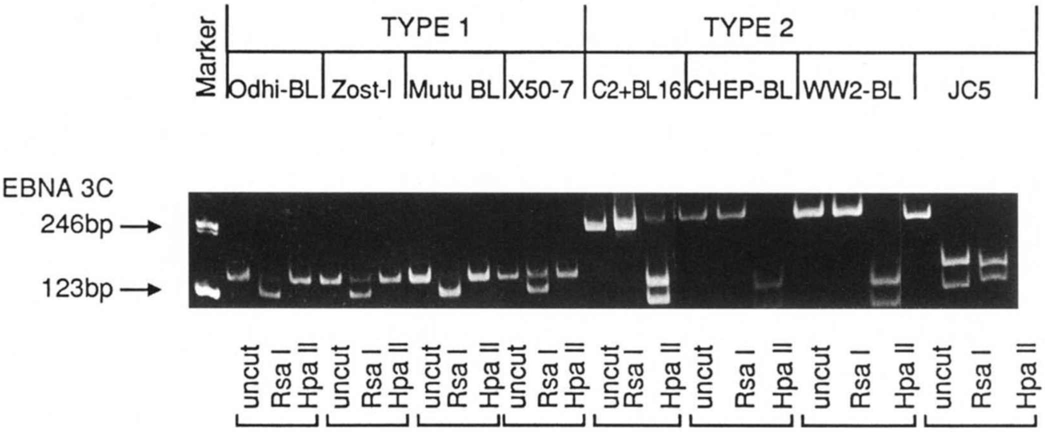

Fig 2. In vitro gene-specific amplification products of EBV EBNA 3C coding region from cell lines carrying EBV type 1 and type 2. Restriction enzyme *Rsa* I recognized specific restriction site identified from the prototype B 95.6 (type 1) from all lines tested, Odhi-BL, Zost-I, Mutu BL, and X 50-7, and for type 2, JC 5. Restriction enzyme *Hpa* II recognized specific restriction site identified from the prototype Ag 876 (type 2) in all 4 type 2 cell lines, C2 + BL16, CHEP-BL, WW2-BL, and JC5 but not in any type 1.

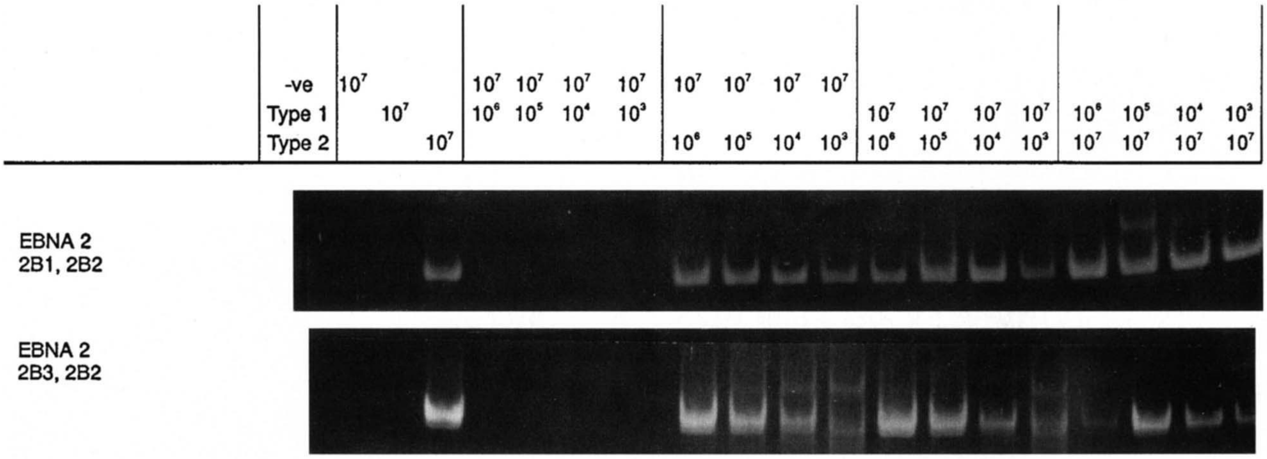

Fig 3. The EBV type 2 results of amplification from EBNA 2 coding regions assessed following DNA extraction from an EBV-negative cell line and cell lines possessing EBV strain type 1 (IB4) and strain type 2 (JC5). Both primer combinations (2B1/2B2 and 2B3/2B4) gave detection of type 2-positive cells as low as 10^3 cells in a background of 10^7 type 1-positive cells or 10^7 EBV-negative cells.

Using these protocols on the clinical material, EBV strain typing was performed in samples from 25 of the children with LMP1-positive HD using EBNA 3C-specific primers. Representative data are illustrated in Fig 5. Seventeen of 25 HD biopsies (eg, 4, 5, and 14) yielded a clear type 1 product identifiable from both its size of 153 bp and its sensitivity to *Rsa* I digestion. One biopsy appeared to yield both type 1 and type 2 amplification products (no. 20; Fig 5), whereas three of 25 biopsies had only a type 2 signal (data not shown). A small fraction of biopsies (three of 25) had no detectable EBNA 3C amplification.

Because EBNA 3C type detection is not optimal with these particular primers, the experiments were then extended using the more sensitive EBNA 2 type 2-specific primer combinations, 2B1/2B2 and 2B3/2B4. This showed that, in fact, 18 of the original 25 biopsies did contain detectable EBNA 2 type 2 sequences; this included nine biopsies already clearly identified as type 1-positive using the sensitive EBNA 3C primers. Results for five representative biopsies (2, 3, 7, 9, and 14) with evidence of such dual infection are shown alongside appropriate controls in Fig 6. In each case, the type 2 specificity of the 2B1/2B2-amplified product was confirmed using diagnostic *Mnl* I digestion (Fig 7).

PCR typing data for all 25 biopsies are shown in Table 4.

In situ hybridization. We therefore asked to what extent EBV-positive cells in HD biopsy samples might consist of two populations: (1) malignant cells and (2) other bystander cells in the nonmalignant infiltrate. In situ hybridization was therefore performed on five biopsies for which PCR analysis had shown evidence of dual type 1/type 2 EBV infection. In situ hybridization showed strong nuclear reactivity in Reed-Sternberg and Hodgkin cells in all five biopsies of formalin-fixed, paraffin-embedded archival lymph nodes using a probe complementary to

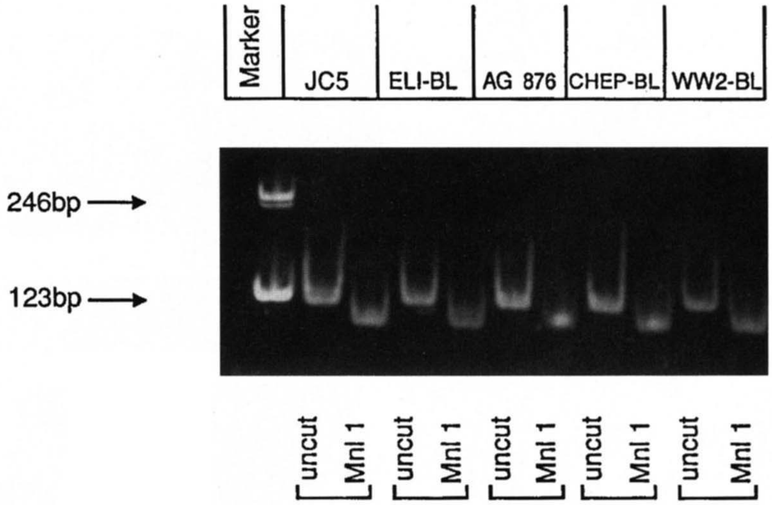

Fig 4. In vitro gene-specific amplification products of the EBV EBNA 2 coding region from cell lines carrying EBV type 2 using 2B1, 2B2 primers. Restriction endonuclease digestion products cleaved using *Mnl* I specific for type 2.

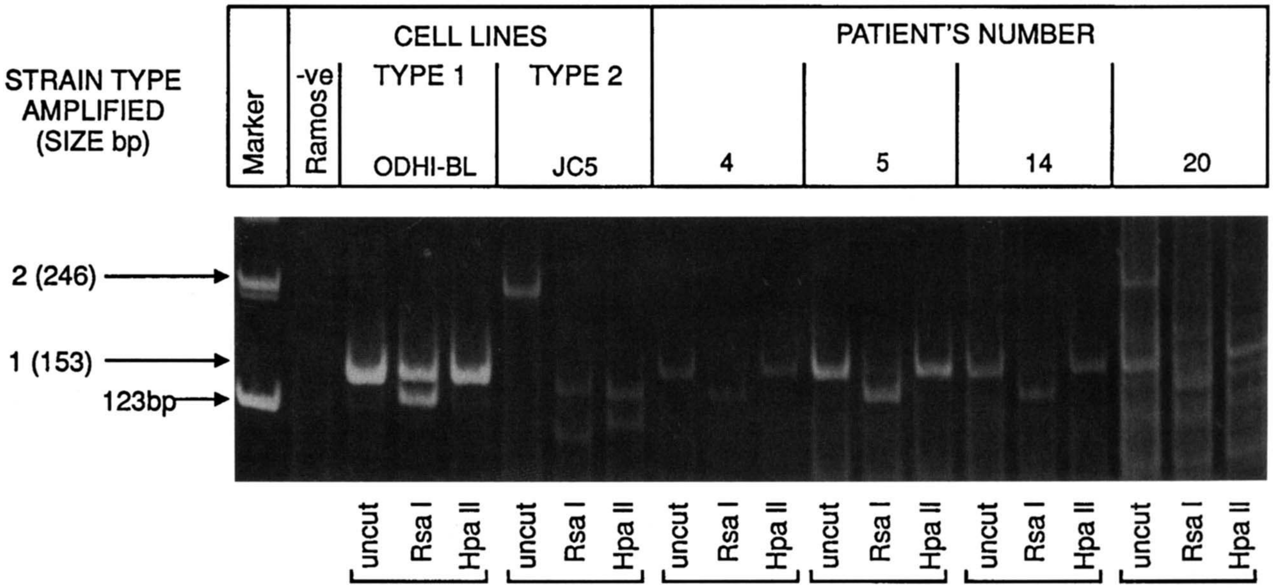

Fig 5. Amplification of DNA from EBNA 3C coding region of the EBV genome from DNA extracted from Formalin-fixed, paraffin-embedded lymph nodes with HD. Restriction enzymes *Rsa* I and *Hpa* II confirmed specificity of the PCR product. EBV-negative cell line Ramos, EBV type 1-positive cell line ODHI-BL, and EBV type 2-positive cell line JC5 are shown as control. Biopsies 4, 5, and 14 gave a clear type 1 product, and biopsy 20 gave both type 1 and type 2 amplification products.

EBER 1 + 2 (Fig 8A). Although the number of EBER-positive cells was higher than the number of LMP1-positive cells in parallel sections, the vast majority of these EBER-positive cells appeared to be Reed-Sternberg and Hodgkin cells, recognized by their characteristically large nuclear size and by Ki-1 positivity in consecutive sections (Fig 8B). In each of the biopsies, only a few small lymphocytes (Ki-1-negative) were hybridized with the EBER 1 + 2 probe (Fig 8A *v* B).

DISCUSSION

In developing countries such as those in Africa, HD is a relatively common malignant lymphoproliferative disorder with an earlier primary peak of incidence and a higher propor-

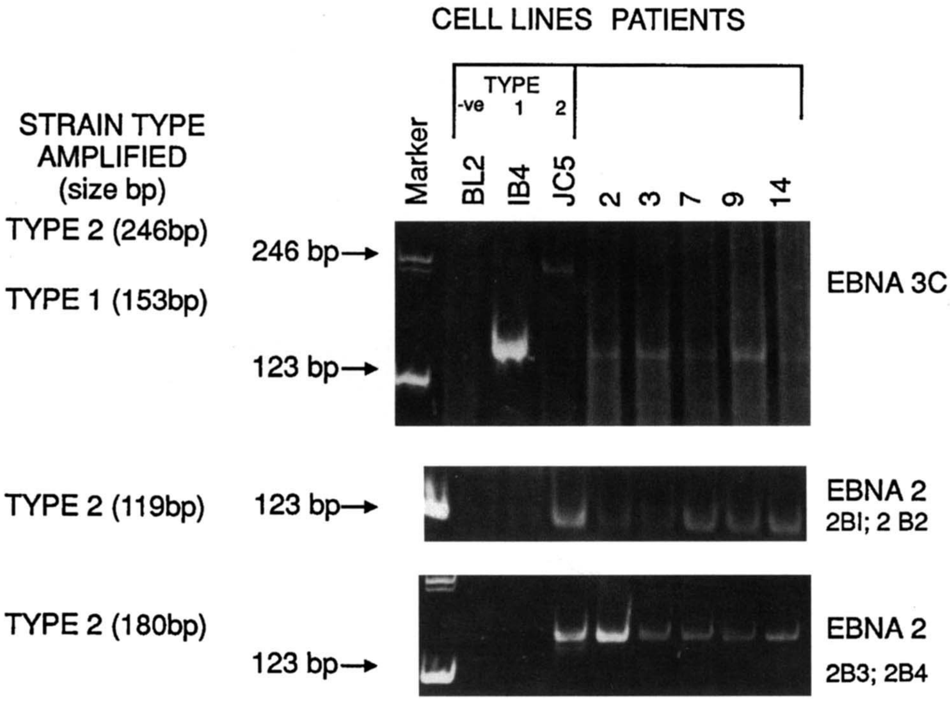

Fig 6. Amplification of DNA from EBNA 3C coding region and EBNA 2 coding region of the EBV genome from DNA extracted from Formalin-fixed, paraffin-embedded lymph nodes with HD. EBNA 3C type primers were not optimal for EBV strain type 2 detection. EBNA 2 type 2-specific primer combinations, 2B1/2B2 and 2B3/2B4, showed that biopsies 2, 3, 7, 9, and 14 did in fact contain detectable EBNA 2 type 2 sequences.

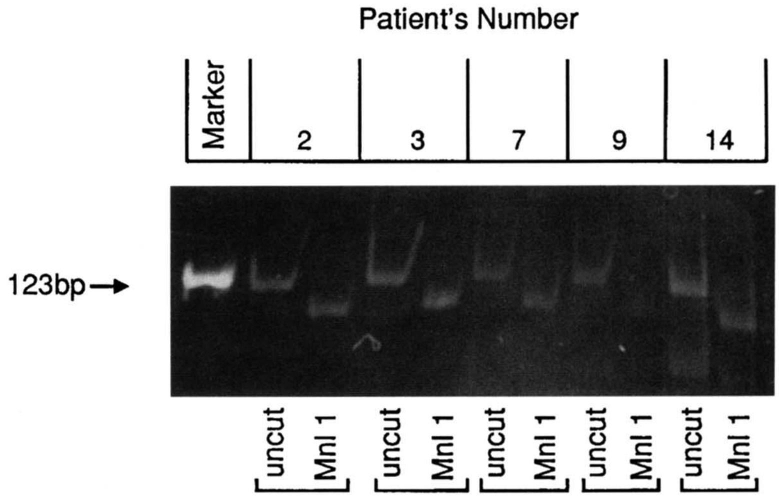

Fig 7. Specificity of the PCR-amplified product of EBNA 2 primers confirmed using diagnostic *Mnl* I digestion.

tion of cases with advanced disease and unfavorable histology than in other parts of the world.[31,32] In Kenya, as in other sub-Saharan countries, HD is primarily a pediatric problem, with 49% of all patients aged less than 20 years and approximately 20% of the patients less than 10 years old.[33]

Although a link between this pattern of HD in developing countries and EBV has been proposed, only a few direct detection studies have been performed in children.[34,35] It is therefore of great interest that our results have shown that 100% of the Kenyan children tested had EBV in their malignant cells. Interestingly, in Kenyan adults with HD, we found that only 63% were LMP1-positive.

Previous studies have shown evidence of EBV in the malignant tissues of 50% to 90% of adults with HD from Denmark, the United Kingdom, and the United States.[9,12,15] In children, EBV positivity was present in 37 of 74 (50%) cases from the United Kingdom,[17] nine of 16 (56%) from the United States,[35] seven of eight (87%) from Saudi Arabia,[36] 18 of 25 (72%) from Brazil,[36] 17 of 19 (87%) from Peru,[34] and 11 of 11 (100%) from Honduras.[35] Armstrong et al[36]

Table 4. Results of EBV Strain Typing From LMP1-Positive HD in Children From Kenya

Identification No.	Histology No.	Age (yr)	Histologic Subtype	EBNA 3C		EBN A2		Strain Type
				Type 1	Type 2	B1, B2	B3, B4	
1	7,611/81	4	LD	+				1
2	1,275/81	5	NS	+		+	+	1 + 2
3	2,332/81	8	MC	+		+	+	1 + 2
4	1,363/81	14	NS	+				1
5	4,285/81	14	MC	+				1
6	1,696/81	14	LD		+	+	+	2
7	6,922/81	15	NS	+		+	+	1 + 2
8	822/82	6	LP				+	2
9	1,412/82	12	LD	+		+	+	1 + 2
10	6,444/82	13	MC	+				1
11	8,507/83	5	LD	+				1
12	8,435/83	4	MC		+	+		2
13	8,656/83	4	MC			+		2
14	1,453/83	6	NS	+		+	+	1 + 2
15	4,060/83	7	NS		+	+	+	2
16	6,327/83	8	NS	+				1
17	1,114/83	8	MC			+	+	2
18	111/83	15	NS	+		+	+	1 + 2
19	3,114/84	7	LD	+		+	+	1 + 2
20	2,706/84	11	MC	+	+	+	+	1 + 2
21	358/87	14	MC			+	+	2
22	2,641/88	5	NS	+		+	+	1 + 2
23	1,651/88	10	MC			+	+	2
24	2,943/88	12	MC	+				1
25	4,117/91	10	LD	+		+	+	1 + 2

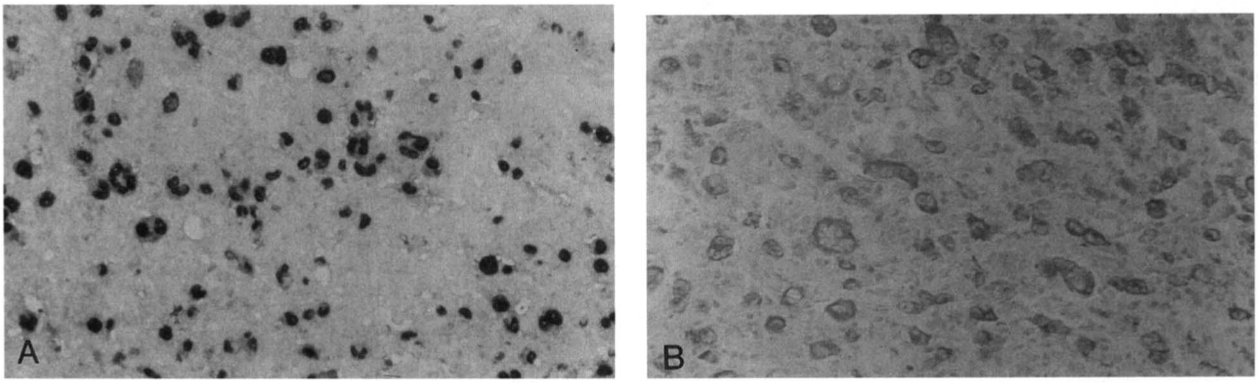

Fig 8. (A) RNA in situ hybridization using EBER 1 + 2 oligonucleotide probe. Positive signal is in Reed-Sternberg cells, Hodgkin cells, and only a few positive infiltrating lymphocytes. Hybridization signal detected with alkaline phosphatase/NBT BCIP. (B) CD30 positivity in Reed-Sternberg cells and Hodgkin cells. (Counterstained with hematoxylin. Original magnification × 250.)

have suggested that HD in children and young adults has different etiologies and that EBV is more likely to be involved in the pathogenesis of pediatric cases. Our studies from Kenya would support this hypothesis. It seems probable that EBV is acquired at a very young age in children in tropical Africa, and this may account for the epidemiological features of HD in this setting, particularly its higher incidence in the young age group.

At least two EBV strain types have been identified, and they differ in the latent infection cycle genes EBNA 2[37] and EBNA 3A, 3B, and 3C.[19] Initial seroprevalence studies and analyses of EBV DNA in lymphoblastoid cell lines indicated that the EBV strain type 2 is unusual in Western Europe and the United States but common in Africa and New Guinea.[38] Results of recent investigations have indicated that EBV strain 2 infection may be more prevalent in the United States than previously believed.[39] The prevalence of type 1 virus infection in the healthy adult population in Kenya was studied by Young et al,[22] who showed that 19 of 25 established spontaneous lymphoblastoid cell lines carried type 1 virus and six cell lines had type 2 virus. However, because type 2 cells are difficult to establish in vitro, this may have underestimated the true incidence of type 2 virus in the population.

Studies of EBV in HD in adults from various countries have shown that type 1 virus was generally present.[40] However, type 2 virus was reported in three of 10 Australian adult immunocompromised patients with HD.[41] A study of Algerian adults with HD, in which DNA extracted from fresh lymph nodes was tested using a PCR technique, was the first report to reveal the coexistence of both types 1 and 2 EBV, in 14 cases.[42]

The EBNA 3C gene primers we used were efficient for detecting type 1 virus, but they failed to detect type 2 virus as efficiently, whether present alone or as a dual infection with type 1. We believe that a mutual suppression may exist whereby the two strain types compete for the common primers, such that the tendency is for the more abundant strain type to inhibit amplification of the other strain; this is particularly apparent when type 2 is in the minority. Using EBNA 2 gene primers, we were able to increase the efficiency of detecting the type 2 strain and thereby identified dual infection in 10 of 25 children with HD. It therefore seems likely that previous studies using different primers have failed to detect dual infections, either because of priming inefficiency or because of mutual competition as experienced with the EBNA 3C primers.

There have been no previous reports of EBV strain-typing in pediatric HD. In the Kenyan children studied, we found only type 1 virus in seven cases and only type 2 in eight cases, but 10 (40%) of the Kenyan children tested had dual infections. Our results are contradictory to the supposed monoclonal EBV origin of HD. However, a recent report has detected a polyclonal origin of malignant cells within HD tissues. These results suggest that the polyclonal population of Reed-Sternberg cells arise from continuous recruitment of unrelated B lymphocytes.[43]

HD is now one of the malignancies believed to be associated with human immunodeficiency virus (HIV) infection,[44,46] and there are reports of individuals with acquired immunodeficiency syndrome (without HD) who have had dual EBV infections.[38] Therefore, our further studies of the Kenyan cases will include screening for HIV.

Early acquisition of EBV infection may account for the high incidence and earlier presentation of pediatric HD in tropical Africa. The presence in many patients of dual infections with both type 1 and type 2 virus is of great interest. The prevalence of strain type 2 EBV in African Burkitt's lymphoma has been described previously.[29] This could reflect poor socioeconomic status leading, for example, to immunocompromise due to malnutrition. Malaria and HIV infection are the other factors that provide an opportunity for the less aggressive type 2 virus to establish an infection.

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REFERENCES

1. Henle G, Henle W: The virus as etiologic agent of infectious mononucleosis, in Epstein MA, Achong BG (eds): The Epstein-Barr Virus. Berlin, Germany, Springer-Verlag, 1979, p 297

2. Magrath I: Pathogenesis of Burkitt's lymphoma. Adv Cancer Res 55:133, 1990

3. Raab-Traub N, Flynn K, Pearson G, Huang A, Levine P, Lainer A, Pagano J: The differentiated form of nasopharyngeal carcinoma contains Epstein-Barr virus DNA. Int J Cancer 39:25, 1987

4. Weiss LM, Strickler JG, Warnke RA, Purtilo DT, Sklar J: Epstein-Barr viral DNA in tissues of Hodgkin's disease. Am J Pathol 129:86, 1987

5. Anagnostopoulos I, Herbst H, Niedobitek G: Demonstration of monoclonal EBV genome in Hodgkin's disease and Ki-1 positive anaplastic large cell lymphoma by combined Southern blot and in situ hybridization. Blood 74:810, 1989

6. Müller N: An epidemiologist's view of the new molecular biology findings in Hodgkin's disease. Ann Oncol 2:23, 1991 (suppl)

7. Lange BB, Arbeter A, Hewtson J: Longitudinal study of Epstein-Barr virus antibody titers and excretion in pediatric patients with Hodgkin's disease. Int J Cancer 22:521, 1978

8. Weiss LM, Movahed AM, Warnke RA, Sklar J: Detection of Epstein-Barr viral genomes in Reed-Sternberg cells of Hodgkin's disease. N Engl J Med 320:502, 1989

9. Jarrett RF, Gallagher A, Jones DB, Alexander FE, Krajewski AS, Kelsey A, Adams J, Angus B, Gledhill S, Wright DH, Cartwright RA, Onions DE: Detection of Epstein-Barr virus genomes in Hodgkin's disease: Relation to age. J Clin Pathol 44:844, 1991

10. Shibata D, Hansmann ML, Weiss LM, Nathwani BN: Epstein-Barr virus infections and Hodgkin's disease: A study of fixed tissues using the polymerase chain reaction. Hum Pathol 22:1262, 1991

11. Samoszuk M, Ravel J: Frequent detection of Epstein-Barr viral deoxyribonucleic acid and absence of cytomegalovirus deoxyribonucleic acid in Hodgkin's disease and acquired immunodeficiency syndrome-related Hodgkin's disease. Lab Invest 65:631, 1991

12. Wright C, Reid AH, Tsai MM, Ventre KM, Murari PJ, Frizzera G, O'Leary TJ: Detection of Epstein-Barr virus sequence in Hodgkin's disease by the polymerase chain reaction. Am J Pathol 139:393, 1991

13. Brousset P, Chittal S, Schleifer D, Icart J, Payen C, Huguet FR, Voigt JJ, Delsol G: Detection of Epstein-Barr virus messenger RNA in Reed-Sternberg cells of Hodgkin's disease by in situ hybridization with biotinylated probes on specially processed modified acetone methyl benzoate xylene (ModAMex) sections. Blood 77:1781, 1991

14. Kieff E, Liebiwitz D: Epstein-Barr virus and its replication, in Fields BN, Knipe DM (eds): Virology (ed 2). New York, NY, Raven, 1990

15. Pallesen G, Hamilton-Dutoit SJ, Rowe M, Young LS: Expression of Epstein-Barr virus latent gene products in tumour cells of Hodgkin's disease. Lancet 337:320, 1991

16. Herbst H, Dalenbach F, Hummel M, Niedobitek G, Pileri S, Mü-Lantz N, Stein H: Epstein-Barr virus latent membrane protein expression in Hodgkin and Reed Sternberg cells. Proc Natl Acad Sci USA 88:4766, 1991

17. Weinreb M, Day PJR, Murray PG, Raafat F, Crocker J, Parkes SE, Coad NAG, Jones TJ, Mann JR: Epstein-Barr virus (EBV) and Hodgkin's disease in children: Incidence of EBV latent membrane protein in malignant cells. J Pathol 168:365, 1992

18. Dambaugh T, Hennessy K, Chamnankit L, Kieff E: U2 region of Epstein-Barr virus DNA may encode Epstein-Barr nuclear antigen 2. Proc Natl Acad Sci USA 81:7632, 1984

19. Sample J, Young LS, Martin B, Chatman T, Kieff E, Rickinson AB, Kieff E: Epstein-Barr virus types 1 and 2 differ in their EBNA-3A, EBNA-3B and EBNA-3C genes. J Virol 64:4084, 1990

20. Rickinson AB, Young LS, Rowe M: Influence of the Epstein-Barr virus nuclear antigen EBNA 2 on the growth phenotype of virus transformed B cells. J Virol 61:1310, 1987

21. Zimber U, Aldinger HK, Lenoir GM, Vuillaume M, Knebel-Doeberitz L, Desranges C, Wittman P, Freese U, Bornkamm G: Geographical prevalence of two types of Epstein-Barr virus. Virology 154:56, 1986

22. Young LS, Yao QY, Rooney CM, Scully TB, Moss DJ, Rupani H, Laux G, Bornkamm GW, Rickinson AB: New type B isolates of Epstein-Barr virus from Burkitt's lymphoma and from normal individuals in endemic areas. J Gen Virol 68:2853, 1987

23. Chang KL, Chen Y-Y, Shibata D, Weiss LM: Description of an in situ hybridization methodology for detection of Epstein-Barr virus RNA in Paraffin embedded tissues, with survey of normal and neoplastic tissues. Diag Mol Pathol 1:246, 1992

24. Lukes RJ, Craver LF, Tall TC: Report of the Nomenclature Committee. Cancer Res 26:1311, 1966

25. Rowe M, Evans HS, Young L, Rickinson AB: Monoclonal antibodies to the latent membrane protein of Epstein-Barr virus reveal heterogeneity of the protein and inducible expression in virus-transformed cells. J Gen Virol 68:147, 1991

26. Murray PG, Young LS, Rowe M, Crocker J: Immunohistochemical demonstration of the Epstein-Barr virus-encoded latent membrane protein in paraffin sections of Hodgkin's disease. J Pathol 166:1, 1992

27. Maniatis T, Fritsch EF, Sambrook J: Molecular Cloning: A Laboratory Manual (ed 2). Cold Spring Harbor, NY, Cold Spring Harbor Laboratory, 1989

28. Waford A, Pringle JH, Henderson SD, Lauder I: Southern blot analysis of DNA extracted from formol-saline fixed and paraffin wax embedded tissue. J Pathol 154:889, 1988

29. Aitken C, Sengupta SK, Aedes C, Moss DJ, Scully TB: Heterogeneity within the EBNA 2 gene in different strains of EBV. J Virol 75:95, 1994

30. Khan G, Coates PJ, Kangro HO, Slavin G: Epstein-Barr virus (EBV) encoded small RNAs: Targets for detection by in situ hybridisation with oligonucleotide probes. J Clin Pathol 45:616, 1992

31. Olweny CLM, Katongole-Mbidde E, Küre CF, Lwga SK, Magrath I, Ziegler JL: Childhood Hodgkin's disease in Uganda: A 10 year experience. Cancer 42:787, 1978

32. Lorraine ML: Hodgkin's disease in Kenya. Cancer 61:189, 1988

33. Riyat MS: Hodgkin's disease in Kenya. Cancer 69:1047, 1992

34. Chang KL, Albujar PF, Chen Y, Johnson RM, Weiss LM: High prevalence of Epstein-Barr virus in the Reed-Sternberg cells of Hodgkin's disease occurring in Peru. Blood 81:496, 1993

35. Ambinder RF, Browning PJ, Lorenzana I, Levental BG, Cosenza H, Mann RB, MacMahon EME, Medina R, Cardona V, Grufferman S, Olsham A, Levin A, Petersen EA, Blattner W, Levine PH: Epstein-Barr virus and childhood Hodgkin's disease in Honduras and United States. Blood 81:462, 1993

36. Armstrong AA, Alexander FE, Paes RP, Morad NA, Gallagher A, Krajewski AS, Jones DB, Angus B, Adams J, Cartwright RA, Onions DE, Jarrett RF: Association of Epstein-Barr virus with pediatric Hodgkin's disease. Am J Pathol 142:1683, 1993

37. Aldinger HK, Delius H, Freese UK, Clarke J, Bornkamm GW: A putative transforming gene of Jijoye virus differs from that of Epstein-Barr virus prototypes. Virology 141:121, 1985

38. Sixby JW, Shirley P, Chesney PJ, Buntin DM, Resnick L: Detection of second widespread strain of Epstein-Barr virus. Lancet 2:761, 1989

39. Armstrong AA, Weiss LM, Gallagher A, Jones DB, Krajewski AS, Angus B, Brown G, Jack AS, Wilkins BS, Onions DE, Jarrett RF: Criteria for the definition of Epstein-Barr virus association in Hodgkin's disease. Leukemia 6:869, 1992

40. Gulley ML, Eagan PA, Quintanilla-Martinez L, Picado AL, Smir BN, Childs C, Dunn CD, Craig FE, Williams JW Jr, Banks

PM: Epstein-Barr virus DNA is abundant and monoclonal in the Reed-Sternberg cells of Hodgkin's disease: Association with mixed cellularity subtype and Hispanic American ethnicity. Blood 83:1595, 1994

41. Boyle MJ, Vasak E, Tschuchnigg M, Turner JJ, Scully T, Penny R, Cooper DA, Tindall B, Sewell WA: Subtypes of Epstein-Barr viruses (EBV) in Hodgkin's disease: Association between B-type EBV and immunocompromise. Blood 81:468, 1993

42. Bouzid M, Belkaid MI, Colona P, Bouguermouh AM, Ooka T: Co-existence of the A and B types of Epstein-Barr virus DNA in lymph-node biopsies from Algerian patients with Hodgkin's disease and non Hodgkin's lymphoma. Leukemia 7:1451, 1993

43. Hummel M, Ziemann K, Lammert H, Pileri S, Sabattini E, Stein H: Hodgkin's disease with monoclonal and polyclonal population of Reed-Sternberg cells. N Engl J Med 333:901, 1995

44. Tirelli U, Errate D, Vaccher E, Reppetto L, Rizzardini G, Spina M: Hodgkin's disease in 92 patients with HIV infection: The Italian experience. Ann Oncol 4:69, 1993

45. Rubio R: Hodgkin's disease associated with human immunodeficiency virus infection. Cancer 73:2400, 1994

46. Goldschmidts WL, Bhatia K, Franklin Johnson J, Akar N, Gutierrez MI, Shibata D, Carolan M, Levine A, Magrath IT: Epstein-Barr virus genotypes in AIDS-associated lymphomas are similar to those in endemic Burkitt's lymphomas. Leukemia 6:875, 1992