Analysis of p16 (CDKN2/MTS-1/INK4A) Alterations in Primary Sporadic Uveal Melanoma
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PURPOSE. To define more clearly the role of the tumor suppressor gene p16 in uveal melanoma by determining the relative contribution of all known mechanisms of p16 inactivation in this tumor.

METHODS. A comprehensive genetic analysis of the p16 gene was performed in 33 primary sporadic ciliochoroidal and choroidal melanomas. Fourteen highly polymorphic microsatellite markers surrounding the p16 locus on chromosome 9p21 were used for the microsatellite analysis. Sequence analysis of the p16 gene was performed on those tumors with 9p21 loss of heterozygosity. To investigate methylation as an alternative mechanism of inactivation of p16, methylation-specific polymerase chain reaction was performed on all tumor DNA samples.

RESULTS. Loss of heterozygosity (LOH) was found in 8 of 33 (24%) uveal melanomas. No evidence of a second region of LOH that did not include the p16 locus was found. Four cases had hemizygous losses including markers both distal and proximal to p16. Homozygous deletion of the p16 gene was detected in the 4 remaining cases by microsatellite analysis. Sequence analysis revealed no p16 mutations in the tumors with hemizygous loss of p16. Methylation of the 5' CpG island of p16 was found in one tumor with 9p21 LOH and in another without LOH.

CONCLUSIONS. p16 inactivation by HD or methylation occurs in 27% of uveal melanomas, representing the most common molecular genetic alteration identified thus far in uveal melanoma. (Invest Ophthalmol Vis Sci. 1999;40:779-783)

Uveal melanoma is the most common primary intraocular malignancy in adults and the second most common site of origin of malignant melanoma.1 Although many of the clinical features and histopathologic indicators of uveal melanoma have been established, little is known about the genetic alterations that are involved in the development of uveal melanoma and the progression to metastatic melanoma. Malignant transformation during tumor progression is known to result from a series of genetic changes.2 Determining the nature and timing of these changes in uveal melanoma will aid in understanding the biology of this tumor type and could lead to the development of new diagnostic and therapeutic strategies.

In human cancer, the frequency of inactivation of the tumor suppressor gene p16, located on chromosome 9p21, is reported to be second only to inactivation of p53.3 Germ-line mutations of p16 are found in about half of patients with familial cutaneous melanoma, and p16 mutations have been found in many cutaneous melanoma cell lines.2,4 Although loss of heterozygosity (LOH; usually due to deletion of one allele at a given locus) of 9p21 is one of the most frequent genetic alterations identified in human cancer, intragenic mutations of p16 have been detected infrequently in many primary cancers with LOH at 9p21.4 Instead, very small homozygous deletions (HDs) of p16 have been detected in these cancers using mic-

References

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PCR Amplification
pigments after phenol/chloroform extraction were addition-

Inactivation of p16 also occurs by promoter hypermeth-

methylation.\textsuperscript{10,19} The methylation of 5' regulatory regions composed of CpG islands leads to repression of gene transcription.\textsuperscript{10} With the exception of X-inactivation and parental imprinting, CpG islands are not generally methylated in normal cells.\textsuperscript{11,12} However, methylation of specific regulatory genes appears to play a role in tumorigenesis. Methylation of the 5' CpG island of p16 was identified and associated with complete transcriptional block and p16 inactivation in many common human cancers.\textsuperscript{8,13} In some tumors, p16 promoter methylation and inactivation occurs quite frequently. For example, methylation occurs in approximately 21% of primary head and neck tumors and correlates with the absence of p16 protein by immunohis-

In contrast to familial cutaneous melanoma, no germline mutations of p16 have been found in patients with familial uveal melanoma.\textsuperscript{15} However, 9p21 loss has been demonstrated in some uveal melanomas by comparative genomic hybridiza-

Inactivation of pl6 also occurs by promoter hypermeth-

MATERIALS AND METHODS
Choroidal Melanomas and Constitutional DNA
Thirty-three paraffin blocks containing specimens of histolog-

Normal and tumor tissue was digested with sodium
dodecyl sulfate/proteinase K and extracted with phenol/

PCR Amplification
DNA from tumor and normal tissue was analyzed for LOH or

Sequence Analysis
The four tumors showing LOH at 9p21 but without HD were
analyzed for mutations of the p16 coding sequence by direct
sequencing. p16 was amplified in two segments as described
using primers 2F and 1108R for exon 1 and primers 42F and
551R for exon 2.\textsuperscript{5} The PCR amplification conditions were for 1 minute at 95°C, 1 minute at 55°C, and 1 minute (exon 1) or 2 minutes (exon 2) at 72°C for 40 cycles and 72°C for 4 minutes with the addition of 10% dimethyl sulfoxide to the reaction mixture. Amplification was confirmed by agarose gel electrophoresis, and amplified products were purified by ethanol precipitation.

Using [\textsuperscript{32}P] ATP 5' end-labeled sequencing primers and the AmpliCycle sequencing kit (Perkin-Elmer, Roche Molecular Systems Inc., Branchburg, NJ), the amplified products were sequenced according to manufacturers instructions with the addition of 10% dimethyl sulfoxide. The PCR conditions used for sequencing were as follows: 1 minute at 95°C, 1 minute at 56°C, and 1 minute at 72°C for one cycle, followed by 1 minute at 95°C, 1 minute at 53°C, and 1 minute at 72°C for 34 cycles. Exon 1 was sequenced with the primer 5'-TGGGGAGAGGG-GAGAGCA. Sequencing primers for exon 2 were 5'-AAGCTTC-CTTTCCGTCATG and 5'-TTCCGGAGACGGCCTTGTTT.
**FIGURE 1.** Patterns of allelic loss in primary uveal melanoma. Eight tumors with 9p21 LOH are shown with tumor location denoted (C, choroidal; CC, ciliochoroidal). All markers are listed from telomere to centromere with the approximate map location indicated to the left. The p16 locus (between markers D9S1749 and D9S1748) is denoted with an arrow. Black rectangle, LOH; white rectangle, retention of both alleles; HD in hatched rectangle, homozygous deletion; and NI, noninformative.

### RESULTS

**Microsatellite Analysis**

Eight of 33 (24%) uveal melanomas showed LOH using 14 highly polymorphic markers surrounding the p16 locus (Fig. 1). Four of 11 (36%) ciliochoroidal tumors and 4 of 22 (18%) choroidal tumors showed 9p21 LOH, and this difference in tumor location was not statistically significant by the Fisher's exact test ($P = 0.39$). The mean maximum tumor dimension of those tumors with 9p21 loss (12 mm) was identical to the mean maximum tumor dimension of all tumors studied.

Homozygous deletion has been reported as the most common method of p16 inactivation in some tumor types. We screened for HDs with the microsatellite markers known to reside within approximately 100 kb of p16. Of the eight tumors with 9p21 LOH, four (numbers 20, 24, 28, and 32) displayed apparent retention of either microsatellite marker D9S1749 or D9S1748 or both (Figs. 1, 2). This pattern of apparent retention has been shown to represent HD of these markers by correlation with Southern blot and FISH analyses. Two other tumors with 9p21 LOH (numbers 10 and 29) were noninformative at one of these critical markers, thereby impairing our ability to detect small HDs in these tumors (Fig. 1).

### Sequence Analysis

Independent deletion of one allele and point mutation of the other allele are thought to completely inactivate most tumor suppressor genes. However, point mutations of p16 have been relatively rare in many sporadic cancers including cutaneous melanoma. The four tumors showing 9p21 loss without HD were sequenced for a p16-inactivating mutation. We sequenced 97% (excluding four codons in exon 3) of the coding region, and no somatic p16 mutations were found (data not shown). Because we carefully microdissected all samples and excluded tumors with HD of the region containing p16, it is unlikely that predominantly normal DNA was amplified and sequenced.

### Methylation Analysis

Methylation of the 5′ CpG island of p16 has not been previously studied in uveal melanoma. Methylation-specific PCR allows the study of small DNA samples from paraffin-embedded tissues that could not previously be analyzed by Southern blot analysis. MSP is based on PCR recognition of a sequence difference, which is created by bisulfite modification of methylated and unmethylated cytosine bases. Unmethylated cytosine is chemically modified to uracil by bisulfite treatment, but methylated cytosine is resistant to modification and remains cytosine. MSP is more sensitive than Southern blot analysis,
allowing the detection of up to one methylated allele/1000 normal alleles at a given CpG island locus.

MSP was performed on all 33 samples of tumor DNA (Fig. 3). DNAs from an unmethylated cancer cell line (011) and a methylated cancer cell line (012) were used as positive controls for the unmethylated and methylated primer sets, respectively. Cell line 011 with only unmethylated alleles amplified with the unmethylated primer set; cell line 012 with only methylated alleles amplified with the methylated primer set, illustrating the specificity of the primer sets. The majority of tumors tested amplified only with unmethylated primers (Fig. 3, tumors 9, 14, and 29). One tumor with 9p21 LOH (number 10) and one tumor without 9p21 LOH (number 40) amplified with the methylation-specific primers, indicating detection of aberrantly methylated alleles in these tumors (Fig. 3). These tumors also amplified with the unmethylated primers, indicating the presence of unmethylated alleles contributed by the presence of a small amount of normal DNA in tumor samples. In previous studies, tumors found to be methylated at the pl6 CpG island by Southern blot analysis were also found to be methylated by MSP.

DISCUSSION

The incidence of uveal melanoma is approximately 6 cases per one million people per year in the United States. Choroidal and ciliochoroidal melanomas pose a significant threat to life, with an overall mortality reported to be 35% in 5 years and 50% in 10 years. Although 8% to 12% of all cutaneous melanomas are familial, familial uveal melanoma (FUM) is rare, with fewer than 100 cases reported in the literature. No constitutional chromosomal abnormalities have been found in 14 patients with FUM. Sequence analysis of p16 in patients with FUM revealed no germline mutations. It appears that if we are to understand the genetic basis of uveal melanoma, we must also study somatic alterations in sporadically occurring tumors.

Inactivation of tumor suppressor genes is common in human cancers. Studies in colon cancer have confirmed the hypothesis that regions of allelic loss may inactivate tumor suppressor genes. In uveal melanoma, the most frequently detected chromosomal losses by comparative genomic hybridization have been monosomy 6q and loss of chromosomal arm 6q (each 45% of 11 tumors studied), followed by loss of chromosomal arm 9p in 3 of 11 tumors (27%). In fact, loss of chromosome arm 9p is one of the most common genetic changes in several tumor types. In an initial attempt to elucidate some of the molecular genetic events that lead to the transformation of a normal uveal melanocyte to metastatic melanoma, we have investigated the contribution of 9p21 LOH and p16 inactivation to the development of uveal melanoma.

We found 9p21 LOH by microsatellite analysis in 24% of tumors studied, consistent with the rate of 9p loss detected by comparative genomic hybridization. A previous report using several different microsatellite markers to study 17 uveal melanomas found LOH at 9p21-22 markers in 6 cases (32%). In contrast to this previous report, we found no evidence of additional regions of allelic loss that did not include the p16 locus (see below). All tumors with 9p21 LOH had loss of contiguous informative markers without interruption by retention of markers (with the exception of small retentions indicative of HD).

In our study, at least one half of uveal melanomas with 9p21 LOH had HD of microsatellite markers flanking the p16 locus. The observed frequency of HD of the approximately 200-kb region between the microsatellite markers D9S1749 and D9S1748 and surrounding p16 is likely to be an underestimate because microdeletions not extending to D9S1749 and D9S1748 would go undetected. In addition, two patients were noninformative at the critical locus D9S1749. Two tumors had
aberrantly methylated p16 promoter regions, which has previously been correlated with transcriptional silencing and absent protein production.\(^8\)

p16 is frequently inactivated by HD or by promoter hypermethylation, whereas inactivation by mutation of p16 is rare in most tumor types. Our failure to detect any inactivating point mutation in uveal melanomas with 9p21 LOH is certainly consistent with observations made in other tumor types including melanoma. Although it is possible that unusual mutations in the promoter or noncoding regions of this gene could be involved in inactivation of p16, this would be unlikely as the predominant mechanism of mutation and has not been previously demonstrated for p16.

It has been suggested that the absence of p16 mutations in uveal melanoma samples with 9p LOH suggests the presence of another tumor suppressor gene in the 9p21 region, which is involved in the pathogenesis of uveal melanoma.\(^29\) The absence of point mutations of p16 in uveal melanoma with 9p21 LOH is not a sufficient argument against p16 as a critical target gene because HDs have been demonstrated in many primary tumors. Although the presence of a second suppressor cannot be ruled out, p16 appears to be at least the major target of inactivation on 9p21 in uveal melanoma; HD and methylation of p16 appear to account for the second inactivation event in the majority of uveal melanomas.

It is interesting to note that the rate of 9p21 LOH in uveal melanoma is roughly half that observed for sporadic cutaneous melanoma (46%-62%).\(^17\),\(^30\) This suggests that uveal melanomas may arise from a series of genetic changes divergent from those contributing to the formation of cutaneous melanoma. Defining the genetic differences between uveal and cutaneous melanoma is important to develop novel diagnostic and treatment options for affected patients. New molecular diagnostic approaches and genetically based anticancer therapies provide the best hope to improve the treatment of this potentially deadly disease.

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References