A Novel Mechanism of Alternative Promoter and Splicing Regulates the Epitope Generation of Tumor Antigen CML66-L

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This report describes the difference in the epitope generation of two isoforms of self-tumor Ag CML66 and the regulation mechanism. We identified a new CML66 short isoform, termed CML66-S. The previously identified long CML66 is referred to as CML66-L. CML66-S shares the C terminus with CML66-L but has its unique N terminus. CML66-S is predominantly expressed in testis, but is also expressed in very low levels in tumor cells, whereas CML66-L is expressed in tumor cells and testis. Differential expression of CML66-L and CML66-S in tumor cells resulted from regulation at transcription, although alternative splicing also participated in the generation of the isoforms. In addition, Ab titers to a CML66-L peptide were significantly higher than that to CML66-S peptide in the sera from patients with tumors. Finally, the Abs to full-length CML66-L in the sera from patients with tumors were correlated with the Abs in the sera from these patients to CML66-L, which is a fusion protein with a CML66-L-specific N terminus. This suggests that the CML66-L isoform is mainly responsible for the epitope generation. Our studies have identified the alternative promoter in combination with alternative splicing as a novel mechanism for regulation of the epitope generation of a self-tumor Ag.


Cancer-testis Ags (CT Ags) are unmutated self-Ags and encoded by an expanding group of genes including MAGE (1) and NY-ESO-1 (2), whose mRNAs are predominantly expressed in 10–40% of a wide range of different cancers and testis (3) but generally not in most other normal tissues (4). Because testis is an immune-privileged site that does not express MHC molecules (5), CT Ags can be practically regarded as tumor specific and highly desirable as targets for immunotherapy (4).

Recently, using sera from patients with chronic myelogenous leukemia (CML) to conduct serological analysis of tumor Ags by recombinant cDNA expression cloning (6–8), we identified a novel, broadly immunogenic tumor Ag, CML66 (9, 10). CML66 encodes a 583-aa protein with a molecular mass of 66 kDa and shows no significant homology to other known genes. CML66 is expressed in a variety of tumor cells. CML66 expression in normal tissues is mostly restricted to testis, suggesting that CML66 may be similar to the Ags in CT Ag group. CML66-specific IgG Ab is found in sera from 18 to 38% of patients with lung cancer, melanoma, and prostate cancer. More importantly, the development of high-titer IgG Ab specific for CML66 correlates with immune-induced remission of CML in a patient who received infusion of normal donor lymphocytes for treatment of relapse. Our findings suggest that CML66 is broadly immunogenic in a wide variety of malignancies and may be a target for Ag-specific immunotherapy (10).

The mechanisms for selective expression of CT Ags in testis and cancers are generally ascribed to demethylation events in cancer (11). However, the mechanism for the immunogenicity of the CT Ags up-regulated in tumor cells remains largely unknown. Elucidation of the mechanism for immunogenicity of CT Ags is very important for future development of Ag-specific immunotherapy. To this end, we attempted to use novel Ag CML66 as a model to explore the mechanism of the immunogenicity of CT Ags. In this report, we identified a CML66 short isoform with 554 aa, termed CML66-S. We refer to the previously identified CML66 of 583 aa as CML66-L. CML66-S shares the C-terminal 544 aa with CML66-L but has its unique 5′-untranslated region (UTR) and its own N terminus. Our results suggest that CML66-L, predominantly expressed in tumor cells, rather than newly identified CML66-S that is mainly expressed in testis, is the dominant immunogenic isoform. Up-regulation of CML66-L, but not CML66-S, in tumor cells is the mechanism for its immunogenicity in patients with tumors. Our studies have identified the alternative promoter in combination with alternative splicing as a novel mechanism for regulation of the epitope generation of a self-tumor Ag.
of Medicine). Serum samples from patients with hormone-refractory advanced prostate cancer were generously provided by Dr. P. Kantoff (Harvard) (10).

Human testis cDNA library screening and 5'-RACE
A human testis cDNA library (1 × 10⁶ phages) (BD Clontech, Palo Alto, CA) was screened with a 0.8-kb 32P-labeled CML66 common-region probe (10). Positive clones were converted into plasmid pTriplEx and sequenced in both strands (Lone Star, Houston, TX). 5'-RACE was conducted by PCR with the human testis Marathon-Ready cDNAs (BD Clontech) as templates. Two antisense primers specific for the 5'-UTR of CML66-S cDNA, SU1 (5'-ATGCTCCAACCCTGGAGTTAAAGACT-3') and the nested primer SU3 (5'-ACGATGCTGAGCTGACCCCTCTAC-3'), were synthesized on the Spt10 polymerase (The Weatherlands, TX). The primer SU1 was paired with the adaptor primer AP1 provided in the kit, and the nested primer SU3 was paired with the adaptor primer AP2, also from the kit. PCR was conducted in a two-temperature touch-down format, with three sets of cycling parameters as follows: 94°C for 30 s and 72°C for 1 min for 5 cycles; 94°C for 30 s and 70°C for 1 min for 5 cycles; and finally, 94°C for 30 s and 68°C for 1 min for 25 cycles. Specific PCR products were subcloned into the PCR-TOPO vector kit (Invitrogen, Carlsbad, CA) and sequenced at Lone Star.

In vitro transcription and translation (TNT)
Bluescript plasmid containing cDNA encoding CML66-L, plasmid pTriplEx containing cDNA encoding CML66-S, and plasmid pTriplEx without cDNA insert (as a negative control) were used (1 μg each) in the in vitro TNT, which were then performed using a TNT T7/T3-coupled system according to the manufacturer's protocol (Promega, Madison, WI) (12).

RT-PCR and PCR cloning
RNA was prepared from tumor cell lines by using RNAzole (Tel-Test, Friendswood, TX). RNA from human testis was purchased from BD Clontech, which includes SMART-amplified cDNA from 64 tumor and corresponding normal tissues from individual patients. The array was screened with a 0.8-kb 32P-labeled CML66 common-region probe (Eastman Kodak, Rochester, NY) and normalized by housekeeping gene control density signals amplified in the same cDNA preparation. A sense primer (25S) specific for the 5’ upstream CML66-S isoform (5’-GGGAGATCGTCCTTATCCTCCGGTTTGAGC-3’) (the underlined italic sequences for cloning purposes) and a second antisense primer (25H) (5’-CCCAGGTAGAAGATGAGAATGTTAACA-3’) specific for the CML66 common region were used for PCR. The PCR with 35 cycles was used for amplification of CML66-S fragment due to its very low abundance. The amplified PCR products (290 bp) were confirmed by using Southern blot hybridization with a 32P-labeled CML66 internal probe (290 bp) were confirmed by using DNA sequencing. The 2.6-kb DNA sequence (KpnI fragment) upstream of the 5’ end of CML66-S, termed promoter CML66-S, was subcloned from a CML66 genomic DNA clone (10) into the KpnI site of pGL-3 luciferase reporter enhancer vector designed for the examination of promoter activity (Promega) was used. The promoter CML66-S was subcloned into the KpnI sites of pGL-3 luciferase reporter enhancer vector in both sense and antisense orientations and confirmed by DNA sequencing. The 2.6-kb DNA sequence (KpnI fragment) upstream of the 5’ end of CML66-S, termed promoter CML66-S, was subcloned from a CML66 genomic DNA clone (10) into the KpnI site of pGL-3 luciferase reporter enhancer vector for both sense and antisense orientations and confirmed by DNA sequencing. 66L promoter-pGL-3 and 66S promoter-pGL-3 vectors as well as three control vectors, including 1) pGL-3 enhancer without any inserts, 2) pGL-3 Basic vector, and 3) pGL-3 Control vector (not shown), were transfected into Hela cells. HCT hepatic carcinoma cells (not shown), and NTERA-2 cl.D1 human testicular embryonal carcinoma cells (American Type Culture Collection, Manassas, VA), respectively. The transfections were performed with the reagent Lipofectamine 2000 (Invitrogen) according to the manufacturer’s instruction. Luciferase activity in transfected cells was measured with the Dual Luciferase system (Promega) on a TD20/20 luminometer (Turner Designs, Sunnyvale, CA). Cotransfected Renilla luciferase control vector (Promega) provides the expression of Renilla luciferase as an internal control. The ratio of the firefly luciferase activity vs the Renilla luciferase activity is used as relative luciferase activity.

Peptide synthesis
A CML66-L-specific peptide (NH2-PCYQUELDAAVAEVK-COOH) and a CML66-S-specific peptide (NH2-LYLQGWSMPVAEVEK-COOH) were synthesized at Sigma-Genosys.

Generation of GST fusion protein
A CML66 fragment encoding the 38 aa in CML66-L-specific N terminus was generated by PCR using the Advantage HF (high-fidelity) PCR kit (BD Clontech), sense primer 385 (5’-CCCCGGGCGGTATCCAGCTGAGC-3’), antisense primer Pro3D (5’-CCCCGGGCGGTATCCAGCTGAGC-3’), and human genomic DNAs (BD Clontech) as the template. The underlined sequences were designed for subcloning purposes. The pGL-3 luciferase reporter enhancer vector designed for the examination of promoter activity (Promega) was used. The promoter CML66-L was cloned into the KpnI sites of pGL-3 luciferase reporter enhancer vector in both sense and antisense orientations and confirmed by DNA sequencing. 66L promoter-pGL-3 and 66S promoter-pGL-3 vectors as well as three control vectors, including 1) pGL-3 enhancer without any inserts, 2) pGL-3 Basic vector, and 3) pGL-3 Control vector (not shown), were transfected into Hela cells. The underlined sequences were designed for subcloning into the EcoRI of GST vector pGEX-3X (Amersham Biosciences, Piscataway, NJ). CML66-L-38 fragment and full-length CML66-S ORF cDNA were fused in frame, respectively, to GST and were confirmed by DNA sequencing. The GST, GST fusion proteins were purified with glutathione Sepharose beads according to the manufacturer’s protocols (Amersham Biosciences) (10).
Mass spectrometric determination of the molecular mass of GST-CML66-S

After being purified using Glutathione Sepharose 4B affinity chromatography (Amersham Biosciences), purified GST-CML66-S was further subjected to size exclusion chromatography on a gel filtration column (Bio-Silect SEC-125 HPLC; Bio-Rad, Hercules, CA). After verification with Western blot using anti-GST Ab, GST-CML66-S containing HPLC fractions (200 μl each) were pooled and freeze-dried on a Virtis (Gardiner, NY) lyophilizer. The molecular mass of GST-CML66-S was determined by mass spectrometry on the matrix-assisted laser desorption ionization-mass spectrometry/time of flight BiFlex III instrument (Bruker Daltonics, Billerica, MA) at Dr. T. Marriott’s laboratory (Mass Spectrometry Center, Department of Chemistry, Rice University, Houston, TX). Briefly, mass spectrometry was performed by mixing 5 mM sample in water (1:2) with sinapinic acid matrix made up in 50:50 acetonitrile:water with 0.1% trifluoroacetic acid added. A volume of 1.5 μl of the sample plus matrix solution was spotted onto the target plate and allowed to evaporate to dryness. The matrix-assisted laser desorption ionization-time of flight-mass spectrometry was obtained on the BiFlex III with a pulsed nitrogen laser (337 nm), in linear positive-ion mode, using a 19-kV acceleration voltage. BSA and GST were used as standards.

Detection of CML66-specific Ab in patient sera by ELISA

ELISA plates (VWR Scientific, Atlanta, GA) were coated with 50 μl of purified proteins, GST, GST-CML66-L, or GST-CML66-L-38, or CML66-L peptide and CML66-S peptide at 5 μg/ml in coating buffer (PBS plus 0.05% sodium azide) overnight at 4°C. ELISAs were performed as previously described (10). OD405 was immediately read on the SpectraMax Plus plate reader (Molecular Devices, Sunnyvale, CA). In addition to using GST-CML66-L full length and GST-CML66-L-38 as coating Ags, each sera sample was also tested against GST alone as a control. The ratio of the OD405 GST-CML66-L full length/OD405 GST or OD405 GST-CML66-L-38/OD405 GST was used to determine the specific activity above background, as the results previously reported (9, 10, 15). An OD405 ratio higher than 3 SD above the mean ratio of OD405 (test Ag)/OD405 GST of normal donor sera was interpreted as positive. The specificity of positive samples was also confirmed by demonstrating inhibition of reactivity by preincubation of patient sera with purified recombinant GST-CML66-L or GST-CML66-L-38, respectively. Similarly, the OD405 ratio of the OD405 GST-CML66-L peptide/OD405 CML66-S peptide was used to determine the specific activity against CML66-L. An OD405 ratio of OD405 CML66-L peptide/OD405 CML66-S peptide higher than 3 SD above the mean ratio of OD405 was interpreted as positive.

Results

Predominant expression of novel CML66 short form, CML66-S, in normal testis

In our previous studies (10), we observed a double-band structure of CML66 in human testis RNA by Northern blot, one with a size of 2.4 kb and one with a size of 2.1 kb. The observed single band of β-actin, as an RNA quality control, in human testis in the same Northern blot suggested that there are two CML66 transcripts with different sizes, a long CML66 transcript and a short CML66 transcript, in a good quality of RNAs from human testis (10). In contrast, only the longer transcript of CML66 with a size of 2.4 kb was found in tumor cell lines, such as erythroleukemia cell line K562, colorectal adenocarcinoma cell SW480, and six other tumor cells shown previously (10), suggesting that these two cell line K562, colorectal adenocarcinoma cell SW480, and six other tumor cells shown previously (10), suggesting that these two
Predominant expression of CML66-L but not CML66-S in tumor cells

Previously, Northern blot analysis with CML66 common-region probe showed that the expression of CML66-L was limited to human testis but not tumor cells or any other normal tissues (10). By using semiquantitative RT-PCR, as shown in Fig. 2A, the expression of CML66-S was found mostly in testis but only detected in very low levels, even after 35 cycles, in tumor cell lines, including kidney cancer line A549, breast cancer line MCF7, lymphoid leukemia line Jurkat, and erythroleukemia line K562, which were verified by Southern blot hybridization with a CML66-specific cDNA probe with no overlap with PCR primers (not shown). In contrast, CML66-L transcripts and the control housekeeping gene GAPDH were detected in all four tumor cell lines and tested with 30 cycles, which corresponded to the previous report (10). This result suggested that CML66-S was specifically expressed in testis but expressed at barely detectable levels in tumor cells.

Previous results on CML66-L expression were derived from Northern blot using RNAs purified from tumor cell lines (10). To examine CML66-L expression in tumor cells from patients, hybridization analyses of the matched tumor/normal expression array were performed with $^{35}$S-Methionine-labeled in vitro TNT products of CML66-L and CML66-S cDNAs separated on SDS-PAGE and revealed by autoradiography. The cloning vector without cDNA insert was used as a control in TNT. CML66-S cDNA can be transcribed and translated into a protein with an apparent molecular mass of 63.5 kDa, slightly smaller than that of CML66-L (66 kDa). The arrows show bands of CML66-L and CML66-S, respectively. C. The mass spectra of GST-CML66-S fusion protein. On the right side, a schematic representation of GST-CML66-S fusion protein is shown together with the CML66-S mass (63,297 Da) calculated by subtracting the the GST mass (26,881 Da) from the GST-CML66-S mass (90,178 Da). D. Schematic representation of overall structure of CML66 gene locus. By comparison of CML66-L and CML66-S cDNA sequences with the sequence of the human genomic clone RP11-122A21, an overall structure of the CML66 gene locus was generated. The CML66 gene has a total of 11 exons and spans a 91.6-kb-long region. The CML66 common region is encoded by exons 3–11. Therefore, CML66-L is encoded by all of the exons except exon 2 (exons 1 and 3–11). In contrast, CML66-S is encoded by all of the exons except exon 1 (exons 2–11). E. Schematic representation of alternative promoter and alternative splicing mechanisms in the generation of isoforms CML66-L and CML66-S. In addition to alternative promoter functioning in the transcription of the CML66-L-specific 5' transcripts encoded by exon 1 driven by CML66-L promoter, or the CML66-S-specific 5' transcripts encoded by exon 2 driven by CML66-L promoter, the alternative splicing mechanism also participates in splicing either exon 1 transcripts into the isoform-shared exons 3–11 to make CML66-L transcripts, or exon 2 transcripts into the isoform 3–11 to make CML66-S transcripts. The schematic organizations of isoforms CML66-L transcripts and CML66-S transcripts are also presented.
that the CML66-L promoter may locate upstream from position −280. These results corresponded well with the following promoter mapping analysis. In the human CML66 locus genomic sequence (GenBank accession no. AC021237) upstream of CML66-5′-UTR, with a promoter prediction software TSSW human poly II recognition using the TRANSFAC database (Baylor website; http://mbcr.bcm.tmc.edu/databases.html), computer analyses indicated that in the sequence upstream of CML66-L start codon (+1), there are a TATA box structure (−289) and several transcription factor binding sites (20), including c-ETS-1 (−320), p53 (−387), NF-κB (−446), AP2 (−456), and SPI (−501), suggesting that the DNA portion may be a promoter responsible for CML66-L transcription, termed CML66-L promoter. In addition, the detailed 5′-RACE of CML66-S showed that three CML66-S 5′-RACE clones had a 98-bp sequence, whereas the other three clones had the same sequence but 12 bp shorter. Staggered starts in the 5′ end of CML66-S 5′-RACE clones suggest that the transcription of the CML66-S-specific transcripts can be driven by an alternative promoter upstream of CML66-S, followed by alternative splicing of the 3′ end of CML66-S-specific transcripts into the 5′ end of CML66 transcripts encoded by CML66 common exons 3–11. This conclusion was further supported by the finding that there are no sequences sharing between CML66-L 5′-UTR and the CML66-S 5′-UTR, suggesting that CML66-S-specific transcription was driven by a CML66-S-specific promoter rather than CML66-L promoter. Similar search for a potential promoter for CML66-S transcription in the sequence of the intron 1 (GenBank accession no. AF521134) showed there were no any TATA box structures in 2.6 kb, even in the whole intron 1 (4 kb), which was confirmed with another promoter software PROSCAN (National Institutes of Health website; http://bimas.dccc.nih.gov/molbio/index.html). However, it is noteworthy that several transcription factor-binding sites were found in the sequence of the CML66-S promoter, including NF-κB (−341), TATA box binding protein (−321), Pit-1 (−319), Pu.1 (−200), C-Myb (−52), and GATA-1 (−18). Although there is no TATA box-based promoter, the existence of several transcription factor binding sites in the CML66-S promoter implies that it may have TATA box-less promoter activity as demonstrated in other genes (21).

We hypothesized that predominant expression of CML66-L, but not CML66-S, in tumor cells may partially result from the differential promoter activities of the two promoters. To test this hypothesis, we adopted a luciferase reporter assay to examine the promoter activities of CML66-L promoter and CML66-S promoter. As shown in Fig. 3, C and D, the representative results from the experiments repeated four times showed that the 1.8-kb CML66-L promoter in the sense orientation had strong promoter activities compared with the antisense-oriented CML66-L promoter control and the no-insert vector control in both Hela cells and HCCT cells (not shown). The strength of sense-oriented CML66-L promoter was in a level equivalent to that of SV40 promoter in pGL-3 Control vector (the positive control, not shown) (22, 23). In contrast, CML66-S promoter in the sense orientation had much lower promoter activities in comparison to that of CML66-L promoter in Hela cells and HCCT cells, the ratio of CML66-L promoter activities vs CML66-S promoter activities was 38:1 in Hela cells, and similar results were obtained in HCCT cells (not shown). These results corresponded well with the sequence analysis regarding the TATA box and transcription factor binding site structure of CML66-L promoter and CML66-S promoter. However, it is notable that the CML66-S promoter activities (mean ± 2 SD, 2.28 ± 0.88 in Hela cells) were statistically higher than that of CML66-S (p < 0.05) in the antisense orientation control (mean ± 2 SD, 0.70 ± 0.29) and no insert vector control (mean ± 2 SD, 0.74 ± 0.35) in these tumor cells. These results suggest that CML66-S promoter had very low promoter activities in both tumor cells. The CML66-S promoter may be functional in testis, as suggested by RT-PCR results in Fig. 2A. To test whether CML66-S promoter has a higher activity in the testis-derived cell line than that in Hela cells and HCCT cells, we performed a luciferase reporter assay to examine the promoter activities of CML66-L promoter and CML66-S promoter in NTERA-2 cl.D1 human testicular embryonal carcinoma cells (American Type Culture Collection). We found that CML66-S promoter activities in NTERA-2 cl.D1 testicular carcinoma cells were seven times higher than that in Hela cells and HCCT cells (Fig. 3D). The ratio of CML66-L promoter activities vs CML66-S
promoter activities in NTERA-2 cl.D1 testicular carcinoma cells (Fig. 3D) was decreased to 6.7:1 from 38:1 in Hela cells and HCCT cells (C). The results further confirmed the functional activities of CML66-S promoter in tests. The difference between CML66-L promoter activity and CML66-S promoter activity in NTERA-2 cl.D1 testicular carcinoma cells may result from their structural and functional differences and the malignancy of the testicular carcinoma cells. The transcription results of CML66-L promoter and CML66-S promoter in tumor cells corresponded well with the expression data of both CML66-L and CML66-S transcripts detected with semiquantitative RT-PCR and cDNA array in tumor cells (Fig. 2). These results suggest that the predominant expression of CML66-L, but not CML66-S, in tumor cells mainly results from the difference of RNA transcriptions driven, respectively, by CML66-L promoter and CML66-S promoter in tumor cells.

**Epitope generation of CML66 contributed mostly by CML66-L but not CML66-S**

CML66-L may be the dominant Ag epitope generation form in comparison to CML66-S in patients with tumors. To directly test this issue, 15-mer CML66-L-specific peptide was synthesized with the N-terminal 9 aa unique to the N terminus of CML66-L and the 6 aa from the CML66 common region (Fig. 4A). In comparison, the 15-mer CML66-S-specific peptide that has the 9 aa from the N terminus of CML66-S and the 6 aa from CML66 common region in its C terminus, which are the same as those in CML66-L peptide, was also synthesized. The OD_{405} ratio of the OD_{405} CML66-L peptide/OD_{405} CML66-S peptide was used to determine the specific reactivity against CML66-L. An OD_{405} ratio of OD_{405} CML66-L peptide/OD_{405} CML66-S peptide higher than 3 SD above the mean ratio of OD_{405} was interpreted as positive. As
shown in Fig. 4B, the ELISA results demonstrated that there were no significant differences in IgG Ab responses to CML66-L peptide and CML66-S peptide in the sera of normal donors. The mean OD\textsubscript{405} ratio plus 3 SD of Abs to CML66-L peptide/Abs to CML66-S peptide in normal controls was 1.094. In contrast, the OD ratios of Abs to CML66-L peptide/Abs to CML66-S peptide in the sera from CML66-L/H11001 patients with tumors (four with CML and three with prostate cancer) were significantly higher than the mean plus 3 SD in normal donors. The CML66-L\textsuperscript{+} patients with tumors were chosen based on the previous results showing positive Abs responses to CML66-L full-length recombinant protein (not shown) (10).

**FIGURE 4.** Immunogenicity of CML66 contributed mostly by CML66-L, but not CML66-S. A. Design of CML66-L peptide and CML66-S peptide. The arrow indicates the splice site in CML66-L and CML66-S, respectively. The 15-mer CML66-L-specific peptide covering the splicing site was synthesized with the N-terminal 9 aa unique to the N terminus of CML66-L and the C-terminal 6 aa (underlined) in the CML66 common region. In comparison, the 15-mer CML66-S peptide, consisting of the N-terminal 9 aa from the CML66-S and the C-terminal 6 aa from CML66 common region (underlined), was also synthesized. B. Positive Ab responses to the CML66-L-specific peptide but not to the CML66-S peptide in patients with tumors. The mean OD\textsubscript{405} ratio plus 3 SD of Abs to CML66-L peptide/Abs to CML66-S peptide in normal controls was 1.094. In contrast, the OD ratios of Abs to CML66-L peptide/Abs to CML66-S peptide in the sera from CML66-L\textsuperscript{+} patients with tumors (four with CML and three with prostate cancer) were significantly higher than the mean plus 3 SD in normal donors. The CML66-L\textsuperscript{+} patients with tumors were chosen based on the previous results showing positive Abs responses to CML66-L full-length recombinant protein (not shown) (10). C. Schematic representation of GST fusion proteins of GST-CML66-L full length and GST-CML66-L-38. D. Positive correlation of Ab responses to CML66-L-specific N terminus with that to full-length CML66-L. The OD\textsubscript{405} ratio of GST-CML66-L over GST was considered as the normalized Ab response to CML66-L\textsuperscript{+}. Similarly, the OD\textsubscript{405} ratio of GST-CML66-L-38 over GST was considered as the normalized Ab response to CML66-L-38. The mean plus 3 SD of the OD\textsubscript{405} ratios of GST-CML66-L full length over GST from 10 normal donors are calculated as the upper limit (1.235) of the normal range of Ab responses to CML66-L full length. Similarly, the mean plus 3 SD (1.163) of the OD\textsubscript{405} ratios of GST-CML66-L-38 over GST from 10 normal donors is also calculated. Ab responses to CML66-L or CML66-L-38 in sera from patients with tumor, including 11 patients with CML and 7 patients with prostate cancer, higher than the normal ranges are considered as positive. The experiments were repeated three times, and the representative results are shown. For eight patients (A–H) with tumors whose sera had both positive IgG Ab responses to CML66-L full length and positive IgG Ab responses to CML66-L-38, the OD\textsubscript{405} ratios of GST-CML66-L full length/GST and the OD\textsubscript{405} ratios of GST-CML66-L-38/GST were listed in a table in the lower panel of D. The results show that Ab responses to CML66-L-38 in patients with tumors are correlated with those to CML66-L full length.
CML and three with prostate cancer) were significantly higher than that of the mean plus 3 SD in normal donors (p < 0.01). In addition to the OD_{405} ratios of CML66-L peptide/CML66-S peptide (Fig. 4B), the mean OD_{405} plus 3 SD of CML66-S peptide in the sera of normal donors was 0.129. The OD_{405} readings in the sera of patients with tumors were all <0.126, suggesting that sera from patients with tumors had no significant IgG Ab responses to CML66-S peptide. Our previous ELISA data with the full-length CML66-L showed that these patients with tumor had positive IgG Ab responses to CML66 (not shown) (10). The results suggest that IgG Ab responses to CML66-L peptide in patients with tumors were significantly higher than that to the CML66-S peptide, and suggest that CML66-L is the dominant immunogenic form.

Furthermore, we hypothesized that if CML66-L is the dominant immunogenic form, specific Ab responses to CML66-L should be correlated with the specific Abs to the CML66-L-specific N-terminal region. To test this hypothesis, we constructed a CML66-L-specific GST fusion protein by fusing the cDNA encoding the N-terminal 38 aa of CML66-L onto the C terminus of GST. In addition to the DNA sequences of cDNA inserts in GST fusion protein vectors, the authenticity of GST-CML66-L full length constructed previously (10) and GST-CML66-L-38 were confirmed by Western blot with anti-GST Ab (not shown) and N-terminal protein sequencing (not shown). Among eight patients, including four patients with CML and four patients with prostate cancer whose specific Abs to CML66-L full length were statistically higher, all eight patients also had statistically higher Ab titers to CML66-L-38. The OD_{405} ratios of GST-CML66-L full length/GST and the OD_{405} ratios of GST-CML66-L-38/GST for all of the eight positive samples (A–H) were listed in Fig. 4D. These results demonstrated that specific Ab responses to CML66-L were well correlated with the specific Abs to CML66-L-38. Preincubation of patient sera with purified recombinant GST-CML66-L full length or GST-CML66-L-38 specifically inhibited ELISA activity, but preincubation with GST alone did not reduce reactivity measured by ELISA (not shown), suggesting that the Ab responses in patient sera to CML66-L or CML66-L-38 are specific. Taken together, these results further confirmed that CML66-L, predominantly expressed in tumor cells, is mainly responsible for epitope generation of this tumor Ag.

Discussion

The transcription of CT Ags in tumor cells was found to be associated with general demethylation in tumor cells (24). However, the precise relation between the expression of CT Ags and their immunogenicity in patients with tumors remains largely elusive, although the threshold levels of tumor Ag expression were recently considered to be important for tumor cell recognition by CTLs (25). The expression profile suggested, by the broadened definition of CT Ags that are mostly expressed in testis and a variety of tumor cells, that CML66-L may be a new member of CT Ag group (4, 10). Therefore, we chose CML66 as a model to further study the mechanism of immunogenicity of CT Ags and self-tumor Ags with similar expression pattern. In this report, we identified a new CML66 isoform, CML66-S. CML66-S is exclusively expressed in testis but expressed in tumor cells at much lower levels, whereas CML66-L is highly expressed in tumor cells in addition to testis. A previous report showed a correlation between mRNA levels and protein expression for CT Ags (25). Our data on the immunogenicity of these CML66 isoforms correlated well with the expression of CML66-L and CML66-S in tumor cells, suggesting that RNA levels of CML66 isoforms could be extrapolated to protein values. This conclusion was further supported by the recent results from Dr. J. Ritz’s lab (Harvard) in the examination of CML66-L protein expression in tumor cells from patients with specific mAbs (26). More importantly, the overexpression of CML66-L in tumor cells is associated with the immunogenicity of this Ag in patients with tumors. We recently characterized another new CT Ag termed CML28 (9, 15). Similar to CML66-L, CML28 was broadly immunogenic in patients with tumors, and the immunogenicity of CML28 is likely to be related to the overexpression of its mRNA transcript and protein in tumor cells (15). This mechanism of immunogenicity has been proposed for other CT Ags, such as NY-ESO-1 (27–29) and the MAGE Ags (30).

To test the hypothesis that CML66-L, predominantly expressed in tumor cells, is mainly responsible for epitope generation of this tumor Ag, we have used two approaches. First, we showed that IgG Ab responses to CML66-L peptide in patients with tumors were significantly higher than those to the CML66-S peptide, suggesting that CML66-L is the dominant immunogenic form. It was our intention in choosing the CML66-S-specific peptide as an appropriate control to demonstrate that CML66-L is the dominant immunogenic form, rather than emphasizing that CML66-S, which is hardly expressed in tumor cells, was not immunogenic. Despite the difference in their N-terminal 9 aa, antigenic index analysis of CML66-L peptide and CML66-S peptide with the Jameson-Wolf algorithm (31) (Lasergene; DNASTAR, Madison, WI) indicated that both peptides were very similar in the antigenicity index (not shown). Furthermore, the N-terminal 10 aa from CML66-L or CML66-S are similar in hydrophilicity (not shown). Taken together, the difference in Ab titers to CML66-L peptide or to CML66-S peptide reflects the difference in Ag expression in patients with tumors but not their differences in the antigenicity index per se of the two peptides. Second, we used the GST-fusion protein approach to test our hypothesis that, if CML66-L is the dominant immunogenic form, specific Ab responses to full-length CML66-L should be correlated with the specific Abs to the CML66-L-specific N-terminal region. The short length of the CML66-S-specific N terminus (10 aa) prevented us from using the GST fusion protein approach to compare the CML66-S N terminus with the CML66-L N terminus. In some patients with prostate cancer, the Ab titers to CML66-L were much higher than those to CML66-L-38. These differences may be due to the fact that, first, the common region of CML66-L also contributed to the epitope generation significantly, and second, Ab responses to CML66-L in patients with prostate cancer were stronger than those in patients with CML, as described previously (10).

There are numerous oncogenes to be amplified in human tumors, including ABL, NRAS, and MYCL (32, 33). Ab response against MYCL was shown to correlate with overexpression of the gene (34). In addition, overexpression of self-Ag in patients with tumors and autoimmune diseases is among the major mechanisms to break immune self-tolerance (35–37). Possibly, the overexpression of self-Ags, such as CML66-L, overcomes the threshold of Ag concentration at which an immune response is initiated, as Zinkernagel and coworkers (38, 39) recently suggested. Overexpressed Ags must access the Ag presentation pathway and immune system. Some mechanisms have been proposed (37). First, overexpressed Ags may be released from damaged tumor cells due to spontaneous necrosis and then become available in the extracellular environment for attack by the immune cells, potentially through cross-presentation (40, 41). Alternatively, tumor-expressed Ags can translocate across the intracellular membranes (42) via binding to heat shock protein 70 and enter the membrane exosome for the MHC class II Ag presentation pathway (43).

It is noteworthy that the CML66 gene is located in a complex structure of human genome (8q23) (10), where CML66 promoter region overlaps with that of the gene encoding a small protein DC6
with 102 aa (GenBank accession no. NM_020189) on the antisense strand. However, similar sense/antisense gene structure has been reported for other genes (44). Lack of the significant homology (16% with gaps) in the amino acid sequences and the dissimilarity of the secondary structures and the antigenicity profiles between CML66 and DC6 (not shown) suggest that the DC6 protein could not have any significant contribution to the epitope generation of CML66 proteins, regardless of potential coregulation of the two genes.

Because CML66-L shares the C-terminal 544-aa common region with CML66-S, the comparison of these two forms in the epitope generation had to focus in their distinct N termini, although it was not our intention to emphasize that the contribution to the epitope generation of the Ag by the N-terminal epitope(s) was larger than that in the C-terminal common region. In addition to our findings that up-regulation of tumor Ag CML66-L, but not CML66-S, is the mechanism for the epitope generation, we further elucidate the control mechanism in the regulation of the generation of CML66-L vs CML66-S. Our results suggest that alternative promoter usage in combination with alternative splicing is the mechanism for the differential expression of CML66-L and CML66-S in tumor cells and, ultimately, the epitope generation of the Ag. Alternative use of multiple promoters, each of them associated with a specific 5′-UTR exon in a tissue-specific manner, was reported for other genes, such as fibroblast growth factor-1 (45, 46). A previous report identified breast cancer Ag ING1 with several transcripts (47). In addition, aberrant tumor Ag PDZ-73 isoform expression in tumors together with amplified expression of isoforms and unidentified mutation as three possibilities have been proposed to be the immunogenic event for PDZ-73 (48). Therefore, this regulation mechanism on the immunogenicity of unmutated self-Ags was not unique to the CML66 gene. The regulation mechanism reported in this study could be recognized as one of the major mechanisms for unmutated self-Ags, because more studies are rapidly being accomplished in the postgenomics era with regard to alternative transcription and processing of the tissue-specific expression of isoforms of self-Ags. Some other factors contributing to the immunogenicity of autoantigens and self-tumor Ags have also been proposed (49). For example, antigenic determinants with low avidity in their interaction with the T cells are displayed in thymus, allowing self-reactive T cells to escape into the periphery (50). The low levels of self-reactive T cells in the peripheral repertoire may contribute to immune responses to the concentration changes of self-Ags (51). In this report, we have intentionally demonstrated that the alternative promoter in combination with alternative splicing is a novel mechanism for the regulation of the immunogenicity of self-tumor Ags, which could be of importance in the understanding of potential roles of autoantigens in autoimmune diseases (52) as well as development of self-tumor Ag-based immunotherapy for tumors (53).

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of immunogenicity and location within the three-dimensional structure of the molecule.


