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Expression levels of HMGA2 in adipocytic tumors correlate with morphologic and cytogenetic subgroups

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Abstract

Background: The HMGA2 gene encodes a protein that alters chromatin structure. Deregulation, typically through chromosomal rearrangements, of HMGA2 has an important role in the development of several mesenchymal neoplasms. These rearrangements result in the expression of a truncated protein lacking the acidic C-terminus, a fusion protein consisting of the AT-hook domains encoded by exons 1–3 and parts from another gene, or a full-length protein; loss of binding sites for regulatory microRNA molecules from the 3' untranslated region (UTR) of HMGA2 has been suggested to be a common denominator.

Methods: Seventy adipocytic tumors, representing different morphologic and cytogenetic subgroups, were analyzed by qRT-PCR to study the expression status of HMGA2; 18 of these tumors were further examined by PCR to search for mutations or deletions in the 3'UTR.

Results: Type (full-length or truncated) and level of expression varied with morphology and karyotype, with the highest levels in atypical lipomatous tumors and lipomas with rearrangements of 12q13-15 and the lowest in lipomas with 6p- or 13q-rearrangements, hibernomas, spindle cell lipomas and myxoid liposarcomas. All 18 examined tumors showed reduced or absent expression of the entire, or parts of, the 3'UTR, which was not due to mutations at the DNA level.

Conclusion: In adipocytic tumors with deregulated HMGA2 expression, the 3'UTR is consistently lost, either due to physical disruption of HMGA2 or a shift to production of shorter 3'UTR.

Background

HMGA2 belongs to the high-mobility group A family of non-histone chromosomal proteins. With its three AT-hooks it can bind to the minor groove of AT-rich regions of DNA, affecting the transcription of target genes by modulating the DNA structure and facilitating or inhibiting the organization of enhanceosomes [1-3]. The HMGA2 protein has been shown to have important functions in cellular growth and differentiation, with a particular impact on the progression of the undifferentiated
mesenchyme during fetal development [4]. HmgA2 knock-out mice display reduced body weight with decreased fat levels as well as impaired fibroblast proliferation, whereas transgenic mice expressing activating mutations show somatic overgrowth with gigantism and lipomatosis [5-7]. Similarly, a boy with a constitutional chromosomal rearrangement resulting in deregulation of HMGAA2 displayed a number of features indicative of disturbed mesenchymal differentiation, such as marked somatic overgrowth, skeletal abnormalities and multiple lipomas [8].

Limited studies on the expression patterns of the HMGA2 gene have shown that it is active in most tissues during fetal development, and that it is transcriptionally silent, or at least expressed at undetectable levels, in most adult differentiated tissues [9]. Aberrant deregulation, however, has been identified in a number of neoplasms, notably of mesenchymal origin [2]. In benign mesenchymal tumors, such as lipoma, the deregulation is often due to a cytogenetically visible rearrangement of the HMGAA2 locus in 12q15, resulting in the expression of a truncated protein lacking the acidic C-terminus encoded by exons 4 and 5, a fusion protein consisting of the AT-hook domains encoded by exons 1–3 and more or less extensive parts from another gene, or, less commonly, expression of a full-length protein; apparently, all three forms – truncated, fusion and full-length – of the HMGAA2 protein have transforming potential when expressed in the relevant cell type [6,7,10-15].

The loss of the C-terminal domains was long thought to be the cause of neoplastic transformation, but the finding that some tumor-associated translocations disrupt the 3' untranslated region (3'-UTR) instead of the open reading frame (ORF), resulting in expression of the full-length HMGA2 protein, suggested that separation of repressive sequences in the 3'-UTR from the 5'-part of the gene could be an important mechanism behind transcriptional up-regulation [12,15,16]. Indeed, the 3'-UTR of HMGA2 is known to contain multiple binding sites for the let-7 family of microRNAs, small non-coding RNAs that inhibit gene expression at the posttranscriptional level, and it was recently shown that targeted mutation of these binding sites as well as functional inactivation of let-7 results in up-regulation of HMGA2 by reducing HMGA2 mRNA degradation in the cytoplasm [17,18].

Approximately 75% of conventional lipomas harbor chromosomal rearrangements of 12q13-15, strongly indicating the involvement of HMGA2 in these cases [19]. The remaining lipomas display other aberrations, including recurrent translocations affecting band 6p21, which harbors the HMGAA1 gene, deletions of 13q, and supernumerary ring chromosomes. The importance of HMGA2 expression in these lipomas and other lipomatous tumors, remains poorly investigated. Over-expression of full-length or truncated HMGA2 has been demonstrated in some lipomas without 12q-rearrangement, as well as in atypical lipomatous tumors, but no systematic analysis of the status of HMGA2 in different cytogenetic subsets of lipomas or in other lipomatous tumors has been performed. In the present study, we used fluorescence in situ hybridization (FISH) and quantitative RT-PCR (qRT-PCR) to study the genomic status and expression level of full-length and truncated HMGA2 in various adipocytic tumors, including conventional lipomas, angiolipomas, spindle cell lipomas, hibernomas, atypical lipomas, well-differentiated liposarcomas, and myxoid liposarcomas. All cases expressing full-length HMGA2, as well as a few cases expressing truncated HMGA2 that served as controls, were further analyzed with regard to mutations in the 3'UTR.

Methods
Patients
A total of 73 adipocytic tumors were selected on the basis of their histopathologic diagnosis and/or cytogenetic profile. Due to lack of appropriate material, G-banding and expression analysis of HMGA2 could be performed in only 69 and 70 cases, respectively. Data concerning patient age and sex, location and karyotype are shown in Additional file 1. In brief, the study included five lipomas with translocation t(3;12)(q27;q13-15), five lipomas with t(5;12)(q32-33;q14-15), five lipomas with various other rearrangements of 12q14-15, five lipomas without any of the known specific cytogenetic hallmarks of lipoma, five lipomas with structural rearrangement of 6p21-22, five lipomas with deletion of chromosome arm 13q, five lipomas with ring chromosomes, eight angiolipomas, five spindle cell lipomas, five hibernomas, ten atypical lipomas, five well-differentiated liposarcomas, and five myxoid liposarcomas.

Cytogenetic analyses
Culturing, harvesting, and chromosome banding of the tumor cells were performed as previously described [20]. Karyotypes were described according to ISCN (2009) [21]. The karyotypes of 29 samples have been reported before [19,22-25].

Metaphase FISH analyses
Metaphase FISH was performed on all 18 cases from which unstained metaphase spreads were available, to study the status of the HMGA2 gene. BAC clones RP11-299L9 and RP11-427K2 that span the 5' and 3' ends, respectively, were used (Figure 1). Five cases had been analyzed previously [19,25]. Probes were selected through the UCSC Human Genome Browser genomic maps http://genome.ucsc.edu. Slides were prepared and analyzed and probes labeled as described elsewhere [26]. When applica-
ble, whole chromosome painting probes (Applied Spectral Imaging, Migdal Haemek, Israel) were used to ensure that tumor cells were analyzed.

**DNA and RNA extraction**

Total DNA from frozen tumor tissue and peripheral blood kept at -80°C was extracted using the DNeasy Blood and Tissue kit according to the manufacturer's recommendations (QIAGEN, Hilden, Germany). Total RNA from the same tumor tissue was extracted using the RNeasy Lipid Tissue Mini kit according to the manufacturer's recommendations (QIAGEN) with minor modifications; 400 mg of tissue were used instead of the recommended 100 mg. After transferring the upper aqueous phase to a new collection tube, it was spun down once more at 12 000 × g for 15 min at 4°C.

**cDNA synthesis**

Three micrograms of total RNA were reverse transcribed in a volume of 50 μl for cDNA synthesis, as described previously [19]. Fetal cDNA from kidney, liver, lung, brain, heart, spleen, thymus and skeletal muscle (Clontech, Mountain View, California, USA) were used for RT-PCR.

**Quantitative RT-PCR analyses (qRT-PCR)**

qRT-PCR was carried out to determine the expression level of *HMGA2*. The *HMGA2* TaqMan gene expression assays (Applied Biosystems, Foster City, CA, USA) Hs00171569_m1 (*HMGA2* exons 1–2) and Hs00971725_m1 (*HMGA2* exons 4–5) were used for the qRT-PCR reaction. Human *ACTB* was used as endogenous control for normalization [Human ACTB (beta actin) Endogenous Control FAM/MGB Probe, Non-Primer Lim-
Polymorphisms corresponding nucleotide sequences were analyzed using the identified were verified by sequencing, and the corre-sequencing are listed in Additional file 3. All transcripts analyzed on 2–2.5% agarose gels. Primers used for formed as described [19]. The PCR products were ana-
lyzed for exons 1–2 and 4–5 of HMGA2 [GenBank:NM_003483] were obtained from the ensembl database http://www.ensembl.org/ sequence of the clone with accession number 33;q14-15), two displayed normal signals for the HMGA2 HMGA2 gene was performed on 18 cases (Additional file 1). In brief, of four analyzed lipomas with t(5;12)(q32-33;q14-15), two displayed normal signals for the HMGA2 gene, one showed a split signal, and one showed translo-
cation of the entire HMGA2 gene to chromosome 5 (Figure 2A). Of four lipomas with various aberrations affecting 12q13-15, three had split signals and one had a deletion of the 3'-end of the gene (Figure 2C and 2D). Of three lipomas without any of the recognized cytogenetic hallmarks of lipoma two had normal signals and one a deletion of the 3'-end of the gene. The only analyzed lipoma with a translocation involving 6p21-22 and two angiolipomas had normal signals for HMGA2. Four atypical lipomas with ring chromosomes showed amplification of HMGA2, with more copies of the 5'-end than of the 3'-end; intact signals were consistently found on the normal chromosomes 12 (Figure 2B).

**qRT-PCR**

A total of 70 adipocytic tumors were investigated with qRT-PCR for the expression of HMGA2 exons 1–2 and exons 4–5. Aberrant expression of HMGA2 was defined as a Log10 value of > 1 for exons 1–2 and/or 4–5; expression levels > 10 times higher for exons 1–2 than for exons 4–5 are hereafter referred to as differential expression. Using these criteria, aberrant expression was seen in 47 cases, of which 24 showed differential expression (detailed results in Additional file 1). None of the cases showed aberrant expression of exons 4–5 without simultaneous aberrant expression of exons 1–2. In brief, the expression levels of exons 1–2 were highest among well-differentiated liposarcomas (median Log10 value of 3.55), followed by atypical lipomas (3.46), t(5;12)-lipomas (3.13), t(3;12)-lipomas (3.00), conventional lipomas with ring chromo-
somes (2.80), lipomas with various rearrangements of 12q13-15 (2.65), lipomas without any of the recognized cytogenetic hallmarks of lipoma (1.85), angiolipomas (1.10), del(13q)-lipomas (0.74), lipomas with rearrange-
ments of 6p21 (0.13), myxoid liposarcomas (0.11), spindle cell lipomas (-0.09), and hibernomas (-0.53). Individual expression levels are illustrated in Figure 3.

With regard to the number of cases showing aberrant and differential expression, the results were as follows: of 15 lipomas with cytogenetic rearrangement of 12q13-15 all showed aberrant expression, with differential expression in all five lipomas with t(3;12), one of five lipomas with t(5;12)(q32-33;q14-15), and three of five lipomas with various other rearrangements of 12q13-15. Four of five lipomas without any of the recognized cytogenetic hallmarks of lipoma showed aberrant expression, with differential expression in two. One of five lipomas with rearrangement of 6p21-22 showed differential expression, and of five lipomas with del(13q), two showed aberrant expression with differential expression in one. All 20 lipomatous tumors with ring chromosomes showed abber-
rant expression, with differential expression in two of five conventional lipomas, six of ten atypical lipomas, and two of five well-differentiated liposarcomas. Three of five angiolipomas showed aberrant expression, without any sign of differential expression. None of the five myxoid

**Results**

**Cytogenetics and FISH**

Sixty-nine of the 73 cases were analyzed by G-banding; from four of the cases no short-term cultures were availa-
ble. Metaphase FISH analysis regarding the status of the HMGA2 gene was performed on 18 cases (Additional file 1). In brief, of four analyzed lipomas with t(5;12)(q32-33;q14-15), two displayed normal signals for the HMGA2 gene, one showed a split signal, and one showed translo-
cation of the entire HMGA2 gene to chromosome 5 (Figure 2A). Of four lipomas with various aberrations

**Genomic PCR, RT-PCR and Sequence analyses**

PCR and sequencing were performed to study cryptic dele-
tions and point mutations in the HMGA2 3′UTR, harboring the target sites of the let-7 miRNA family (Figure 1), in 18 tumors. These cases included all nine tumors with full-
length HMGA2 expression and from which further material was available, as well as controls showing differential or weak expression of HMGA2. The PCR reaction was per-
fomed as described [19]. The PCR products were ana-
lyzed on 2–2.5% agarose gels. Primers used for sequencing are listed in Additional file 3. All transcripts identified were verified by sequencing, and the corre-
sponding nucleotide sequences were analyzed using the Chromas software [GenBank:NM_003483]. Polymorphisms were identified from the ensembl database http://www.ensembl.org.

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liposarcomas and only one case each of spindle cell lipoma (differential expression) and hibernoma (full-length) showed aberrant expression.

**RT-PCR and genomic PCR**

The expression of the reported 3'UTR of *HMGA2*, divided into three regions covering all eight known binding sites for *let-7*, was studied by RT-PCR in 18 tumors, various fetal tissues and amniocytic cell cultures (Table 1). Of the 18 tumors, nine had aberrant expression of both exons 1–2 and 4–5, four showed differential expression of exons 1–2, two showed weak expression of both exons 1–2 and 4–5, and three had unknown expression status. All three amniocytic cell cultures expressed all three regions of the 3'UTR (see Additional file 4A). In the fetal tissues, expression of Region 1 was found in kidney, liver, lung, spleen, and thymus, but the bands were weak except in kidney. Expression of regions 2 and 3 was seen in all tissues except brain, which also lacked expression of region 1 (see Additional file 5A). Of the tumors, only one (case 10) expressed all three regions, but with very weak expression of region 2. Faint bands for region 1 and/or 3 were seen in nine tumors. In the remaining eight tumors, including two cases with differential expression of *HMGA2*, none of the regions was detected (Table 1, see Additional file 4A). Genomic PCR for the 3'UTR of *HMGA2* was performed in

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**Figure 2**

**Metaphase FISH on four cases regarding the involvement of the *HMGA2* gene.** BAC clones RP11-299L9 (FITC) and RP11-427K2 (Cy3), spanning the 5' and 3' parts, respectively, of *HMGA2* were used. Arrowheads indicate normal chromosomes 12. A) Lipoma (case 10) with a t(5;12)(q33;q14) where the entire *HMGA2* locus was translocated to chromosome 5. A wcp5 probe was used to identify chromosome 5 in tumor cells. The derivative chromosome 12 was present in the metaphase cell, but not included in the picture. B) Atypical lipoma (case 55) with ring chromosome and amplification and split signal of *HMGA2*. Normal signals for *HMGA2* can be seen on the two normal chromosomes 12. C) Lipoma (case 11) with an inv(12)(q14q24) causing a deletion of the 3'-end of *HMGA2*; thus, only the green signal corresponding to RP11-299L9, covering the 5'-part, can be seen. D) Lipoma (case 14) with a t(10;12)(q22;q15) resulting in a split signal for *HMGA2*; the 3' part of the gene is translocated to chromosome 10. A wcp12 was used to identify chromosome 12 in tumor cells.
15 of the tumors that had been studied by RT-PCR; in addition, DNA from peripheral blood was available from six of the cases. PCR products of expected size were seen in all tumors and blood samples (see Additional files 4B and 5B).

**Sequencing**

Sequencing of the 3'UTR of HMGA2 was performed on the 15 tumors in which genomic PCR was conducted to study involvement of the let-7 binding sites. As reference, the sequence with accession number NM_003483 was used [GenBank NM_003483]. In region 1, eight of the 15 tumors were homozygous for G/G, six homozygous for T/T and one heterozygous for T/G for a previously reported polymorphism in position 1280 (reference number rs3741427). In region 2, one tumor was homozygous for C/C, two were homozygous for T/T, and 12 were heterozygous for C/T at position 2416 (reference number rs1042725). In region 3, no mutations were seen.

**Discussion**

Among the 35 conventional lipomas that were analyzed here, four expression patterns were observed: (1) strong (>100-fold) expression of the full-length gene (exons 1–2 as well as 4–5), (2) a truncated gene (only exons 1–2; differential expression), (3) moderate (10–100-fold) expression of the entire gene, and (4) weak/absent expression of any part of the gene. Although we cannot fully exclude that low expression in some case was due to admixture of normal cells, it is of interest to note that the
type of expression pattern varied with cytogenetic sub-
group. All five lipomas with t(3;12) showed strong (log10 
ratio between 2.72 and 3.15), differential expression. The 
t(3;12) is the most common cytogenetic aberration in 
conventional lipoma, resulting in an 
**HMGA2/LPP**
fusion gene. In cases reported in the literature, the fusion gene 
amays always contain exons 1–3 of 
**HMGA2** and, usually, exons 
9–11 of 
**LPP**, which is at odds with the finding of 
increased (log10 ratios 1.04 and 1.49) expression of exons 
4–5 in two of our cases. However, a few reported lipomas 
with t(3;12) have also expressed the reciprocal 
**LPP/HMGA2** chimera and some tumors with rearrangements 
of **HMGA2** express the wild type allele [14,28-31].

In contrast, only one of five lipomas with a t(5;12), the 
second most common translocation in conventional lipoma, 
showed differential expression in the present study; the other four cases all showed aberrant expression of the entire gene. This is in line with previous FISH data on this particular translocation, demonstrating that the genomic breakpoints usually occur outside the **HMGA2** locus [25].

The only case here with differential expression also had a 
split **HMGA2** locus at FISH analysis, supporting the view 
that the molecular outcome of the t(5;12) is heterogeneous. Cytogenetic analyses of conventional lipomas have identified numerous other translocation partners to the 
**HMGA2** locus in 12q [19]. Although only a few of these partners have been examined at the molecular level, it is well known from FISH studies that the breakpoints may occur inside as well as outside **HMGA2**. Thus, it was not unexpected that all five lipomas with variant 12q13-15 
rearrangements in the present study, representing five dif-
ferent recombination partners, showed overexpression of 
**HMGA2** and that some of them had expression of the full-
length gene whereas others had differential expression. 
Interestingly, strong expression of the full-length gene was 
seen in one case with a t(1;12)(p32;q15) and a split FISH 
signal, with the 3’-part of **HMGA2** translocated to 
chromosome 1. Combined, these findings indicate that this 
particular translocation led to the fusion of **HMGA2** with 
a strongly expressed gene in chromosome 1. However, 
high expression of the other, wild type, allele cannot be 
excluded.

The molecular pathways in conventional lipomas with 
rearrangements of 6p or deletions of 13q remain to be

### Table 1: RT-PCR and genomic PCR analyses of the 3’ UTR of **HMGA2**

| Case  | Sample      | Type of **HMGA2** expression | RT-PCR products Region | Genomic PCR products Region |
|-------|-------------|-----------------------------|------------------------|-----------------------------|
|       |             |                             | Region 1 | Region 2 | Region 3 | Region 1 | Region 2 | Region 3 |
|       |             |                             |           |           |           |           |           |           |
| Amniocytes 1 | ND          |                             | +         | +         | +         | ND         | ND         | ND         |
| Amniocytes 2 | ND          |                             | +         | +                 | +         | ND         | ND         | ND         |
| Amniocytes 3 | ND          |                             | +         | +         | +         | ND         | ND         | ND         |
| 4 Lipoma t(3;12) | Differential | (+)                   | -           | +         | (+)           | +         | +         | +         |
| 4 Peripheral blood | ND    |                             | ND         | ND         | ND         | +         | +         | +         |
| 10 Lipoma t(5;12) | Aberrant |                             | +         | (+)         | +         | +         | +         | +         |
| 11 Lipoma der(12q13-15) | Differential | -           | -         | -         | +         | +         | +         |
| 13 Lipoma der(12q13-15) | Aberrant |                             | -         | -         | -         | +         | +         | +         |
| 17 Variant Lipoma | Aberrant |                             | (+)       | -         | (+)           | +         | +         | +         |
| 18 Variant Lipoma | Aberrant |                             | (+)       | -         | -         | +         | +         | +         |
| 18 Peripheral blood | ND    |                             | ND         | ND         | ND         | +         | +         | +         |
| 21 Lipoma der(6p21-22) | Differential | -           | -         | (+)       | ND         | ND         | ND         |
| 26 Lipoma del(13q) | Differential | -           | -         | -         | +         | +         | +         |
| 26 Peripheral blood | ND    |                             | ND         | ND         | ND         | +         | +         | +         |
| 27 Lipoma del(13q) | Aberrant |                             | -         | -         | -         | ND         | ND         | ND         |
| 36 Angiolipoma | Aberrant |                             | (+)       | -         | +         | ND         | ND         | ND         |
| 37 Angiolipoma | Aberrant |                             | -         | -         | (+)       | +         | +         | +         |
| 38 Angiolipoma | Aberrant |                             | -         | -         | (+)       | +         | +         | +         |
| 38 Peripheral blood | ND    |                             | ND         | ND         | ND         | +         | +         | +         |
| 40 Angiolipoma | Weak         |                             | -         | -         | -         | +         | +         | +         |
| 40 Peripheral blood | ND    |                             | ND         | ND         | ND         | +         | +         | +         |
| 41 Angiolipoma | ND          |                             | -         | -         | -         | +         | +         | +         |
| 42 Angiolipoma | ND          |                             | -         | -         | (+)       | +         | +         | +         |
| 43 Angiolipoma | ND          |                             | -         | -         | (+)       | +         | +         | +         |
| 49 Hibernoma | Aberrant |                             | -         | -         | (+)       | +         | +         | +         |

Abbreviations: Aberrant = Log10 value of ≥ 1 for exons 1–2 and exons 4–5; Differential = Aberrant expression of exons 1–2 with ≥ 10 times higher 
expression than for exons 4–5; Weak = Log10 value 0–1 for exons 1–2 and 4–5; + = strong PCR product; (+) = weak PCR product; - = no PCR 
product; ND = not determined.
clarified. It is commonly believed that rearrangements of the HMGA1 gene, located in band 6p21, could substitute for HMGA2 rearrangements, but this has been verified in only a small number of cases, [19,32-34] and no candidate target for 13q-deletions has been identified. The notion that the molecular pathogenesis of these lipomas is different from that in 12q-positive ones was strengthened by the finding here that only one case in each group showed strong HMGA2 expression. Further, indirect support for the hypothesis that most lipomas with 6p21 or 13q-rearrangements develop through pathways that do not involve HMGA2 could be found among the lipomas that showed aberrations that do not belong to any of the known cytogenetic subgroups of conventional lipomas; four of five showed aberrant (log10 ratio 1.80–2.17) expression of the 5′ part or of the entire gene. Thus, most of the non-recurrent cytogenetic aberrations observed are probably secondary changes, accrued during tumor growth.

Ring chromosomes and giant markers (hereafter referred to as rings) constitute the cytogenetic hallmark of atypical lipomatous tumors, and it has been shown that these rings consistently contain amplified sequences from chromosome 12 [35-38]. Occasionally, also tumors diagnosed as conventional lipoma display rings, and it has been debated whether these cases represent highly differentiated atypical lipomatous tumors or whether some are true conventional lipomas with a similar genetic profile [19,36,39-42]. The former interpretation seems the more likely; not only do tumors diagnosed as conventional lipomas with rings share the clinical characteristics of atypical lipomatous tumors (male predominance, larger size, preferential location in the thigh), but the genomic contents of the rings are the same [42-44]. In the present study, the expression of HMGA2 was increased (full-length in three and differential in two) in all five cases diagnosed as conventional lipomas with rings. However, the expression levels (median log10 ratio for exons 1–2, 2.80) were more similar to those seen in lipomas with t(3;12) and t(5;12) (median log10 ratios 3.00 and 3.13, respectively) than in tumors diagnosed as atypical lipomas and well-differentiated liposarcomas (median log10 ratios 3.46 and 3.55, respectively), whereas the fraction of lesions with differential expression was similar in all three tumor entities. This raises the interesting possibility that the level of cellular atypia may be influenced by the level of HMGA2 expression in lipomatous tumors with rings. However, the rings are highly complex chromosome aberrations and it cannot be excluded that the amplification and expression levels of other genes influence the phenotype.

Whereas atypical lipomatous tumors in the extremities seldom recur after surgery and only rarely transform into high-grade lesions, morphologically and cytogenetically identical lesions in the retroperitoneum commonly dedifferentiate, eventually often killing the patient. To emphasize these differences in clinical behaviour, the former are often referred to as atypical lipomas, and the latter as well-differentiated liposarcomas. In the present study, we analyzed ten atypical lipomatous tumors of the extremities and five of the retroperitoneum. They consistently showed high expression of HMGA2, arguing for the importance of deregulated HMGA2 expression also in this subtype of lipomatous tumors [36,45].

Taken together, these results demonstrate that all 35 lipomatous tumors with cytogenetically visible 12q13-15 rearrangements – translocations, inversions, rings – have aberrant expression of HMGA2, and that some of these rearrangements, like the t(3;12), consistently result in differential expression of the first three exons whereas other rearrangements, like the t(5;12), most often lead to expression of the entire gene. The lack of HMGA2 expression in most cases with rearrangements of 6p21 or deletions of 13q strongly support the view that these lipomas develop through other genetic pathways. The consistently high expression of HMGA2 in conventional lipomas with ring chromosomes provides further support for the idea that these tumors belong to the same biologic entity as atypical lipomas and well-differentiated liposarcomas.

As expected, none of the five myxoid liposarcomas, which all had a t(12;16) resulting in a FUS-DDIT3 fusion gene (data not shown), expressed HMGA2. Similarly, most hibernomas and spindle cell lipomas, which at the chromosome level typically show translocations affecting chromosome 11q13 and deletions of 13q, respectively, did not show any deregulation of HMGA2. However, one case each demonstrated moderate expression of the full-length gene (hibernoma, log10 ratio exons 1–2, 1.60) or only of the amino-terminal part (spindle cell lipoma, log10 ratio exons 1–2, 1.76). Although both cases were morphologically typical, it is well known that hibernomas and spindle cell lipomas may contain more or less extensive areas resembling conventional lipomas, presumably reflecting differentiation. Possibly, such areas might be associated with deregulated expression of HMGA2.

Angiolipomas often occur as multiple tumors, and an autosomal dominantly inherited predisposition is apparent in some families [46,47]. Repeated cytogenetic analyses have, with a single exception, resulted in normal karyotypes [23], suggesting that they are either non-neoplastic or that they arise through submicroscopic mutations [46]. In the present study, five cases could be analyzed with regard to expression level of HMGA2, two of which were also studied by FISH; none of the latter
showed any cryptic rearrangement of the HMGA2 locus. In all cases, the expression levels were highly similar for exons 1–2 and 4–5, and the median expression level (log10 ratio 1.10 for exons 1–2) was higher than that in myxoid liposarcomas, hibernomas, spindle cell lipomas, and lipomas with 13q-deletions or 6p21-rearrangements, but lower than that in conventional lipomas with cytogenetically visible 12q-rearrangements. Thus, it seems as if also angiolipomas, at least to some extent, are associated with aberrant HMGA2 expression, but not on the basis of gross chromosomal rearrangements.

To study the role of the 3’UTR for deregulated HMGA2 expression, RT-PCR was performed in 18 lipomatous tumors, including nine with aberrant expression of the full-length gene, four with differential expression, and five with weak or unknown expression (Table 1). The 3’UTR of HMGA2 is 2996 bp long, according to the sequence reported in 1996 by Ashar et al. [GenBank:NM_003483][48]. It contains a number of potential termination sites before the one that ends the reported full-length UTR. In addition, there are 10 AUUUA elements, which are thought to be important for deadenylation and subsequent decay of the mRNA [15]. We are not aware of any previous, systematic in vitro studies of the expression of the 3’UTR, neither in tumors nor in non-neoplastic tissues, but several experimental studies have suggested that the 3’UTR plays an important role in the posttranscriptional regulation of HMGA2. In 2001, Borrmann et al. measured the luciferase activity of the full-length and five different deletion constructs of the HMGA2 3’UTR [15]. They found that truncation of the distal 593 bp reduced the activity, suggesting the existence of positive regulatory elements at the 3′ end of the UTR, but that further deletions significantly increased the luciferase activity. This increase was interpreted to be due to the loss of the AUUUA elements. More recently, it was shown that the 3’UTR of HMGA2 contains eight, functional or putative, binding sites for the let-7 family of microRNAs, and that mutational inactivation of these binding sites increased the mRNA levels of HMGA2 [17,18,49,50]. In line with these findings, it is known that let-7 and HMGA2 expression levels are inversely correlated during embryogenesis. This agrees well with the strong expression of the entire 3’UTR in all amniocytic cell cultures included here. In contrast, only two of the tumors, a lipoma with t(5;12) and a relocated HMGA2 locus and an angiolipoma, showed convincing expression of any of the three regions. The remaining tumors, regardless of morphologic subtype and type of HMGA2 expression, showed only faint expression of no more than two of the three regions investigated, providing further in vivo support for the notion that loss of regulatory sequences from the 3’UTR is essential for aberrant expression of HMGA2 in lipomatous tumors. However, as loss or significant reduction of expression of the 3’UTR was a consistent feature also of tumors with expression of the full-length gene and normal HMGA2 loci at FISH analysis, there must be other mechanisms than chromosomal rearrangements leading to this transcriptional silencing. It was recently shown by Sandberg et al. (2008) that proliferating cells tend to shift from producing longer to shorter mRNA isoforms, and they suggested that a switch to more proximal polyadenylation sites might be a mechanism for these cells to escape regulation by microRNAs [51]. How this shift from expressing mRNAs with full-length 3’UTR, as seen in the amniocytic cultures, to mRNAs without the 3’UTR, or at least with a 3’UTR too short to be detected by the assays used here, is achieved in lipomatous tumors remains to be clarified. Our and others results indicate that the expression of HMGA2 [9,52] as well as its 3’UTR varies from one tissue to another. Based on the present study, however, the lack of 3’UTR expression seems not to be due to mutations within the 3’UTR itself. Furthermore, nor could we find any evidence that a SNP (rs1042725) within the 3’UTR that has been associated with body height [53] has any impact on the development of lipomatous tumors.

**Conclusion**

We have shown that the expression (level and/or type of transcript) of HMGA2 in adipocytic tumors varies with morphologic subtype and cytogenetic background. Thus, transcriptional deregulation was strongly associated with cytogenetically visible involvement of the HMGA2 locus. We also showed that tumors expressing HMGA2 do not express the 3′UTR of the gene, thereby avoiding down-regulation by the let-7 family of microRNAs.

**Competing interests**

The authors declare that they have no competing interests.

**Authors’ contributions**

HB performed the FISH and PCR analyses, collected and analyzed the data and wrote the manuscript. IP and AC assisted in designing the experiments and interpreting the results. DT carried out part of the sequencing and analyses. HAD was responsible for the morphologic classification of the tumors. NM and FM were responsible for the cytogenetic data and for the design of the study. All authors have read and approved the final manuscript.

**Additional material**

**Additional file 1**

Supplementary table: Clinical, cytogenetic, qRT-PCR, and FISH Data on 73 adipocytic tumors

Click here for file [http://www.biomedcentral.com/content.supplementary/1476-4598-8-36-S1.doc](http://www.biomedcentral.com/content.supplementary/1476-4598-8-36-S1.doc)
Additional file 2
Expression pattern of HMG2A exons 1–2 and 4–5 in human adipose tissue. A) exons 1–2 and B) exons 4–5 of HMG2A in human adipose tissue. [Ambion's total Human RNA] showing a late expression pattern, starting after 35 cycles in both amplifications. Three replicates were run. Click here for file
[http://www.biomedcentral.com/content/supplementary/1476-4598-8-36-S2.tiff]

Additional file 3
Supplementary table. Primers for PCR
Click here for file
[http://www.biomedcentral.com/content/supplementary/1476-4598-8-36-S3.doc]

Additional file 4
RT-PCR and genomic PCR for the 3'UTR of HMG2A. RT-PCR and genomic PCR for the 3'UTR of HMG2A in 3 amniotic cell cultures and 18 adipocytic tumors. Click here for file
[http://www.biomedcentral.com/content/supplementary/1476-4598-8-36-S4.tiff]

Additional file 5
RT-PCR and genomic PCR for the 3'UTR of HMG2A. RT-PCR analysis of the 3'UTR of HMG2A in fetal tissues and genomic PCR analysis of the 3'UTR of HMG2A in DNA from peripheral blood from six of the patients with lipomatous tumors. Click here for file
[http://www.biomedcentral.com/content/supplementary/1476-4598-8-36-S5.tiff]

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