

# Comparative Genomic Hybridization of Cancer of the Gastroesophageal Junction: Deletion of 14Q31–32.1 Discriminates between Esophageal (Barrett's) and Gastric Cardia Adenocarcinomas<sup>1</sup>

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## ABSTRACT

Incidence rates have risen rapidly for esophageal and gastric cardia adenocarcinomas. These cancers, arising at and around the gastroesophageal junction (GEJ), share a poor prognosis. In contrast, there is no consensus with respect to clinical staging resulting in possible adverse effects on treatment and survival. The goal of this study was to provide more insight into the genetic changes underlying esophageal and gastric cardia adenocarcinomas. We have used comparative genomic hybridization for a genetic analysis of 28 adenocarcinomas of the GEJ. Eleven tumors were localized in the distal esophagus and related to Barrett's esophagus, and 10 tumors were situated in the gastric cardia. The remaining seven tumors were located at the junction and could not be classified as either Barrett-related, or gastric cardia. We found alterations in all 28 neoplasms. Gains and losses were distinguished in comparable numbers. Frequent loss ( $\geq 25\%$  of all tumors) was detected, in decreasing order of frequency, on 4p (54%), 14q (46%), 18q (43%), 5q (36%), 16q (36%), 9p (29%), 17p (29%), and 21q (29%). Frequent gain ( $\geq 25\%$  of all tumors) was observed, in decreasing order of frequency, on 20p (86%), 8q (79%), 7p (61%), 13q (46%), 12q (39%), 15q (39%), 1q (36%), 3q (32%), 5p (32%), 6p (32%), 19q (32%), Xp (32%), 17q (29%), and 18p (25%). Nearly all patients were male, and loss of chromosome Y was frequently noted (64%). Recurrent high-level amplifications ( $>10\%$  of all tumors) were seen at 8q23–24.1, 15q25, 17q12–21, and 19q13.1. Minimal overlapping regions could be determined at multiple locations (candidate genes are in parentheses): minimal regions of overlap for deletions were assigned to 3p14 (*FHIT*, *RCA1*), 5q14–21 (*APC*, *MCC*), 9p21 (*MTS1/CDKN2*), 14q31–32.1 (*TSHR*), 16q23, 18q21 (*DCC*, *P15*) and 21q21. Minimal overlapping amplified sites could be seen at 5p14 (*MLV12*), 6p12–21.1 (*NRASL3*), 7p12 (*EGFR*), 8q23–24.1 (*MYC*), 12q21.1, 15q25 (*IGF1R*), 17q12–21 (*ERBB2/HER2-neu*), 19q13.1 (*TGFBI*, *BCL3*, *AKT2*), 20p12 (*PCNA*), 20q12–13 (*MYBL2*, *PTPNI*), and Xq25. The distribution of the imbalances revealed similar genetic patterns in the three GEJ tumor groups. However, loss of 14q31–32.1 occurred significantly more frequent in Barrett-related adenocarcinomas of the distal esophagus, than in gastric cardia cancers ( $P = 0.02$ ). The unclassified, "pure junction" group displayed an intermediate position, suggesting that these may be in part gastric cardia tumors, whereas the others may be related to (short-segment) Barrett's esophagus. In conclusion, this study has, first, provided a detailed comparative genomic hybridization-map of GEJ adenocarcinomas documenting new genetic changes, as well as candidate genes involved. Second, genetic divergence was revealed in this poorly understood group of cancers.

## INTRODUCTION

Analyses of cancer incidence data in the United States and Western Europe revealed steadily rising rates over the past decades of adeno-

carcinomas of the esophagus and gastric cardia (1, 2). Overall, cancer of the esophagus is increasing, and stomach cancer is decreasing. However, when analyzed by histological type and subsite the picture is very different. In the esophagus, squamous cell carcinoma rates have remained stable, whereas a rapid increase of adenocarcinoma is observed. In the stomach, cardia shows a very similar pattern to adenocarcinoma of the esophagus, but pyloric-antrum cancer is decreasing. Both esophageal and gastric cardia adenocarcinomas arise around the GEJ.<sup>3</sup> Esophageal adenocarcinoma is strongly correlated with Barrett's esophagus. In Barrett's esophagus, the squamous cell epithelium has undergone metaplastic change to columnar epithelium as a result of long-standing gastroesophageal reflux (3–5). Metaplastic change has also been observed at the GEJ, which might explain the rising frequency at this location (6). Intestinal metaplasia of the gastric cardia has been reported, however, its relation with malignant transformation is presently not clear (7).

GEJ adenocarcinomas share a poor prognosis, due to aggressive tumor behavior, as well as late detection (8, 9). Adenocarcinomas of the GEJ region disproportionately affect white men and less frequently occur among women (1, 10). A 5–6-fold increase has been reported between 1970 and 1990 (11, 12). The simultaneously increased incidence at the different locations suggest that adenocarcinomas of the GEJ are related. Reflux disease has been suggested as an etiological factor not only in esophageal adenocarcinoma, but also in cancer of the gastric cardia (13). Recent epidemiological studies have focused on the role of diet and cigarette smoking. It was found that smoking is a major risk factor for GEJ carcinomas (14). Also, increased fat intake was found to be important in esophageal and gastric cardia cancers (15, 16). In addition, an increasing prevalence of obesity may have contributed to the upward trends in GEJ adenocarcinomas (17).

Cytogenetic studies of series of both gastric and esophageal adenocarcinomas have shown frequent chromosomal rearrangement of 11p13–15 (18) and deletion of 3q (19). In a study of 37 adenocarcinomas in Barrett's esophagus and gastric cardia, loss of the Y chromosome seemed a prominent feature (20). Furthermore, rearrangements were most frequently seen of chromosome arms 1p, 3q, 11p, and 22q. Genetic abnormalities have been extensively documented in the, formerly common, pyloric-antrum type of gastric cancer (e.g., gene amplification; Ref. 21). Ranzani *et al.* (22) detected LOH at 5q, 11p, 17p, and 18q and, with a low frequency, also at 7q and 13q. In these gastric cancers, deletions often occur at the *APC* and *MCC* loci on 5q21 (23). Little is known of LOH in

<sup>3</sup> The abbreviations used are: GEJ, gastroesophageal junction; CGH, comparative genomic hybridization; LOH, loss of heterozygosity; *MCC*, mutated in colorectal cancer; *APC*, adenomatous polyposis coli; *MTS1*, multiple tumor suppressor 1; *DCC*, deleted in colorectal carcinoma; *FHIT*, fragile histidine triad gene; *MLV12*, MoMuLV integration site 2; *NRASL3*, v-*ras* neuroblastoma RAS-like oncogene 3; *EGFR*, epidermal growth factor receptor; *MYC*, v-*myc* myelocytomatosis oncogene; *ERBB2*, oncogene 2; *TGFBI*, transforming growth factor  $\beta$ 1; *BCL3*, B-cell CLL/lymphoma 3; *AKT2*, v-*akt* murine thymoma oncogene 2; *PCNA*, proliferating cell nuclear antigen; *MYBL2*, v-*myb* myeloblastosis-like oncogene 2; *PTPNI*, protein tyrosine phosphatase nonrec. type 1; *TSHR*, thyroid-stimulating hormone receptor; *IGF1R*, insulin-like growth factor 1 receptor; UICC, Union Internationale Contre le Cancer.

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GEJ tumors. In a recent study of adenocarcinoma of the gastric cardia, frequent allelic loss was seen on 3p, 4q, 5q, 8p, 9pq, 12q, 13q, 17p, and 18q (24). Blount *et al.* (25) reported that alleles in chromosomes 5q, 17p, and 18q are involved in esophageal adenocarcinomas with high frequency. Allelotyping studies of esophageal adenocarcinoma have been constructed (26–28). They found frequent loss on 1p, 3q, 6q, 4pq, 5q, 9p, 12pq, 13q, 17p, and 18q. A few *in situ* hybridization studies have been reported on GEJ adenocarcinomas. In an early study, loss of chromosome Y and aneuploidy in gastric adenocarcinomas was shown (29). Hunter *et al.* (30) reported a high percentage of chromosome Y loss in esophageal adenocarcinoma. Krishnath *et al.* (31, 32) described loss of chromosome Y, gain of chromosome 8, and loss of chromosome 17 in esophageal adenocarcinoma. Recently, CGH of GEJ cancers was reported on limited numbers of these neoplasms (33, 34). Gain of chromosome 20 was most frequently found. Furthermore, gain was seen on 6p, 7pq, 8q, and 17q, and loss was observed on 4pq, 5q, and 18q.

We undertook a CGH study to address the following questions: (a) what are the frequent unbalanced genetic abnormalities occurring in GEJ adenocarcinomas? (b) are there differences in the genetic profiles of Barrett-related esophageal adenocarcinomas *versus* gastric cardia cancers? and (c) is it possible to assign candidate genes underlying these neoplasms?

**MATERIALS AND METHODS**

**Patient Material.** We collected 28 adenocarcinomas of the GEJ (*i.e.*, 11 esophageal, 10 gastric cardia, and 7 nonclassifiable cancers). The specimens were fresh-frozen, except four paraffin-embedded samples. The esophageal carcinomas were located in the distal esophagus in the presence of Barrett’s transformed mucosa. The nonclassifiable tumors were situated at the GEJ, and Barrett’s mucosa was not present. The gastric cardia cancers were clearly localized in the proximal stomach. The majority of the GEJ specimens were primary tumors (*n* = 23), but cell lines (*n* = 3; Ref. 35) and xenografts (*n* = 2) were included also (Table 1). Staging of the tumors was performed according to the UICC classification (36).

**CGH.** The 28 specimens were microdissected to enrich for tumor cell content (≥75% of cells). Excised tumor material was minced using a fine scalpel, and digested in extraction buffer [10 mM Tris/HCl (pH 8.0), 100 mM NaCl, 25 mM EDTA, 0.5% SDS, and 300 μg/ml Proteinase K] at 37°C for several hours. DNA was extracted with phenol-chloroform-isoamyl alcohol for at least four times and subsequently precipitated in ethanol, according to standard protocols. DNA was treated with RNase (20 μg/μl in 2 × SSC) for 1 h at 37°C, precipitated, and dissolved overnight in sterile water at 55°C. Concentration, purity, and molecular weight of the DNA was estimated using both UV spectrophotometry and ethidium bromide-stained agarose gels with control DNA series.

The CGH procedure was based on the protocol described by Kallioniemi *et al.* (37) with few modifications, as described previously by us (38). Tumor DNA was direct-labeled with FITC-dUTP, and control male DNA was labeled with lissamine-dUTP (both from DuPont-NEN, Boston, MA) by nick-translation. Each labeled DNA (200 ng) and 10 μg of human Cot-1 DNA (Life Technologies, Inc., Gaithersburg, MD), dissolved in 10 μl of hybridization buffer (50% formamide/2 × SSC/10% dextran sulfate), were hybridized to normal male metaphases and incubated at 37°C for 4 days. Posthybridization washes were performed with 2 × SSC at 37°C, followed by 0.1 × SSC at 60°C. Slides were counterstained with 4,6-diamidino-2-phenylindole (0.5 μg/ml) in Vectashield antifade solution (Vector Laboratories, Inc., Burlingame, CA).

Images of each of the three fluorochromes were collected using an epifluorescence microscope (Leica DM, Rijswijk, the Netherlands) equipped with three single excitation filters, a multibandpass dichroic mirror, a multiband emission filter (P-1 filter set; Chroma Technology, Brattleborough, VT), and a cooled CCD camera (Photometrics, Tucson, AZ). The green, red, and blue images were collected sequentially by changing the excitation filter. Images were saved using a routine built up in SCIL-Image (TNO, Delft, the Netherlands), implemented on a Power Macintosh 8100, and analyzed using QUIPS XL software (Vysis, Downers Grove, IL). For the profiles, losses of DNA sequences are defined as chromosomal regions where the mean green to red fluorescence ratio and its 95% confidence interval is below 0.9, whereas gains are defined as chromosomal regions where this ratio is above 1.1 (a 0.8–1.2 interval was used for the four paraffin-embedded samples). The threshold values were based on measurements from a series of normal controls.

Table 1 Tumor/patient data

Tumor	Age/sex	Site	Type	Differentiation	Stage (UICC) <sup>a</sup>	Barrett
oe33	73/F	Esophagus	Cell line <sup>b</sup>	Poor	T <sub>2/3</sub> N <sub>0</sub> M <sub>0</sub>	Yes
bp1	69/M	Esophagus	Primary	Moderate	T <sub>3</sub> N <sub>0</sub> M <sub>0</sub>	Yes
bp2	49/M	Esophagus	Primary	Moderate	T <sub>3</sub> N <sub>1</sub> M <sub>0</sub>	Yes
bp7	61/M	Esophagus	Primary	Poor	T <sub>3</sub> N <sub>1</sub> M <sub>1</sub>	Yes
bp11	68/M	Esophagus	Primary	Poor	T <sub>3</sub> N <sub>1</sub> M <sub>1</sub>	Yes
ba3	53/M	Esophagus	Primary	Poor	T <sub>3</sub> N <sub>0</sub> M <sub>0</sub>	Yes
ba7	63/M	Esophagus	Primary	Moderate	T <sub>1</sub> N <sub>0</sub> M <sub>0</sub>	Yes
ba10	53/M	Esophagus	Primary	Moderate	T <sub>3</sub> N <sub>1</sub> M <sub>1</sub>	Yes
ba13	65/M	Esophagus	Primary	Poor	T <sub>3</sub> N <sub>1</sub> M <sub>0</sub>	Yes
ba22	73/M	Esophagus	Primary	Moderate	T <sub>3</sub> N <sub>1</sub> M <sub>1</sub>	Yes
ba27	85/M	Esophagus	Primary	Poor	T <sub>3</sub> N <sub>1</sub> M <sub>1</sub>	Yes
oe19	72/M	Cardia	Cell line <sup>b</sup>	Moderate	T <sub>3</sub> N <sub>1</sub> M <sub>0</sub>	No
m2.1	76/M	Cardia	Xenograft <sup>c</sup>	Moderate	T <sub>2</sub> N <sub>2</sub> M <sub>0</sub>	No
ba1	63/M	Cardia	Primary	Well	T <sub>2</sub> N <sub>1</sub> M <sub>0</sub>	No
ba15	57/M	Cardia	Primary	Moderate	T <sub>2</sub> N <sub>1</sub> M <sub>0</sub>	No
ba18	54/M	Cardia	Primary	Poor	T <sub>3</sub> N <sub>1</sub> M <sub>0</sub>	No
ba23	75/M	Cardia	Primary	Moderate	T <sub>3</sub> N <sub>1</sub> M <sub>0</sub>	No
ba26	63/M	Cardia	Primary	Poor	T <sub>2</sub> N <sub>0</sub> M <sub>0</sub>	No
ba32	58/M	Cardia	Primary	Poor	T <sub>3</sub> N <sub>2</sub> M <sub>0</sub>	No
ba33	69/M	Cardia	Primary	Moderate	T <sub>2</sub> N <sub>0</sub> M <sub>0</sub>	No
ba34	75/F	Cardia	Primary	Moderate	T <sub>2</sub> N <sub>2</sub> M <sub>0</sub>	No
oe50	71/F	Junction	Cell line <sup>b</sup>	Poor	T <sub>2/3</sub> N <sub>0</sub> M <sub>0</sub>	No
m4.1	54/M	Junction	Xenograft <sup>c</sup>	Poor	T <sub>3</sub> N <sub>2</sub> M <sub>1</sub>	No
ba11	59/M	Junction	Primary	Poor	T <sub>3</sub> N <sub>2</sub> M <sub>0</sub>	No
ba17	78/M	Junction	Primary	Moderate	T <sub>3</sub> N <sub>0</sub> M <sub>0</sub>	No
ba19	67/M	Junction	Primary	Poor	T <sub>3</sub> N <sub>2</sub> M <sub>0</sub>	No
ba20	44/M	Junction	Primary	Poor	T <sub>3</sub> N <sub>2</sub> M <sub>0</sub>	No
ba21	62/M	Junction	Primary	Moderate	T <sub>3</sub> N <sub>0</sub> M <sub>0</sub>	No

<sup>a</sup> Tumor-node-metastasis classification according to the UICC (36). Adenocarcinomas of the GEJ are classified as gastric cardia. It is important to note that in this classification distal oesophageal adenocarcinomas are relatively overrated in comparison with gastric cancers.

<sup>b</sup> Obtained from the European Collection of Animal Cell Cultures.

<sup>c</sup> Derived from a regional lymph node metastasis.

**Statistical Evaluation.** The two-tailed Fisher's exact test was used for comparison of genetic aberrations in the GEJ tumor groups.

**RESULTS**

Our investigation concerned the CGH evaluation of 28 GEJ adenocarcinomas, (*i.e.*, 11 esophageal, 10 gastric cardia, and 7 nonclassifiable cancers of the junction; Table 1). The esophageal carcinomas were located in the distal esophagus in the presence of Barrett's transformed mucosa. The nonclassifiable tumors were situated at the gastro-esophageal junction, and Barrett's mucosa was not present. The gastric cardia cancers were clearly localized in the proximal stomach. We found multiple alterations in all 28 neoplasms, illustrating the genetic instability of gastrointestinal adenocarcinomas (Fig. 1). Gains and losses were seen in comparable numbers. Frequent loss ( $\geq 25\%$  of all tumors) was detected, in decreasing order of frequency, on 4pq (54%), 14q (46%), 18q (43%), 5q (36%), 16q (36%), 9p (29%), 17p (29%), and 21q (29%). Frequent gain ( $\geq 25\%$  of all tumors) was observed, in decreasing order of frequency, on 20pq (86%), 8q (79%), 7p (61%), 13q (46%), 12q (39%), 15q (39%), 1q (36%), 3q (32%), 5p (32%), 6p (32%), 19q (32%), Xpq (32%), 17q (29%), and 18p (25%). Examples are illustrated in Fig. 2. Nearly all patients were male, which is common in these cancers, and loss of chromosome Y was frequently noted (64%). Recurrent high-level amplifications ( $>10\%$  of all tumors) were seen at 8q23–24.1, 15q25, 17q12–21,

and 19q13.1. The 15q and 19q amplifications have not been reported in other human neoplasms before. Minimal overlapping regions could be determined at multiple locations (Table 2; candidate genes are in parentheses): minimal regions of overlap for losses were assigned to 5q14–21 (*APC*, *MCC*), 9p21 (*MTS1/CDKN2*), 14q31–32.1 (*TSHR*), 16q23, 18q21 (*DCC*, *PI5*), and 21q21. Less frequent (21% of the tumors), but clearly present, was a minimal deleted region on 3p14 (*FHIT*, *RCA1*). Minimal overlapping sites for gains could be seen at 5p14 (*MLV12*), 6p12–21.1 (*NRASL3*), 7p12 (*EGFR*), 8q23–24.1 (*MYC*), 12q21.1, 15q25 (*IGF1R*), 17q12–21 (*ERBB2/HER2-neu*), 19q13.1 (*TGFB1*, *BCL3*, *AKT2*), 20p12 (*PCNA*), 20q12–13 (*MYBL2*, *PTPNI*), and Xq25. The genomic imbalances displayed similar distribution profiles in the three GEJ-tumor groups. However, loss of 14q31–32.1 occurred significantly more frequent in Barrett-related adenocarcinomas of the distal esophagus, than in gastric cardia cancers (Fisher's exact test,  $P = 0.02$ ). The unclassified, pure junction group of tumors displayed an intermediate position (Fig. 3). It suggests that part of these may be gastric cardia tumors, whereas the others may be related to Barrett's transformed mucosa (*i.e.*, the so-called short-segment Barrett's esophagus).

**DISCUSSION**

This study reports the first detailed CGH-map of genetic changes underlying adenocarcinomas of the GEJ. The overall genomic profile,

Fig. 1. Chromosomal ideograms showing the summary of DNA copy number changes, detected by CGH, in 28 adenocarcinomas of the GEJ (esophagus, 11; gastric cardia, 10; junction/nonclassifiable, 7). Losses are displayed on the left of the ideogram (red), gains are shown on the right (green). Frequent loss is detected on 4pq, 5q, 9p, 14q, 16q, 17p, 18q, 21q, and Y. Frequent gain is observed on 1q, 3q, 5p, 6p, 7p, 8q, 12q, 13q, 15q, 17q, 18p, 19q, 20pq, and Xpq.

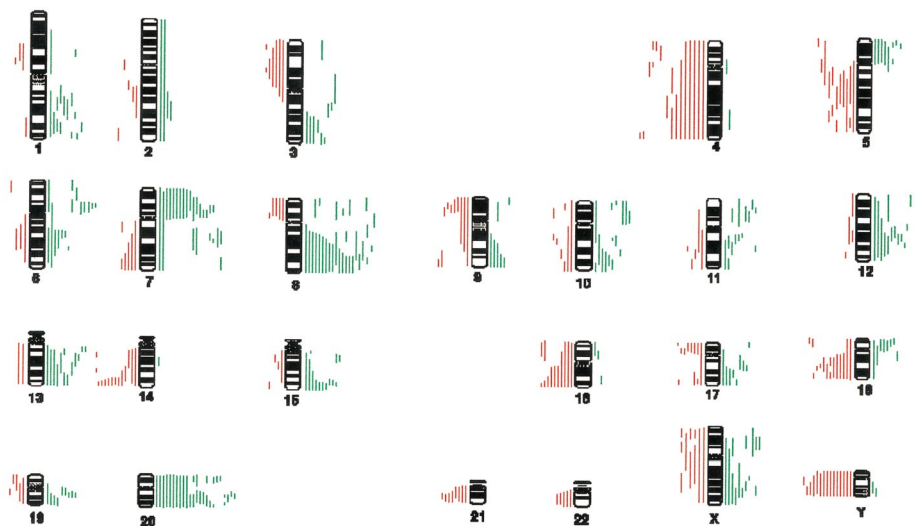
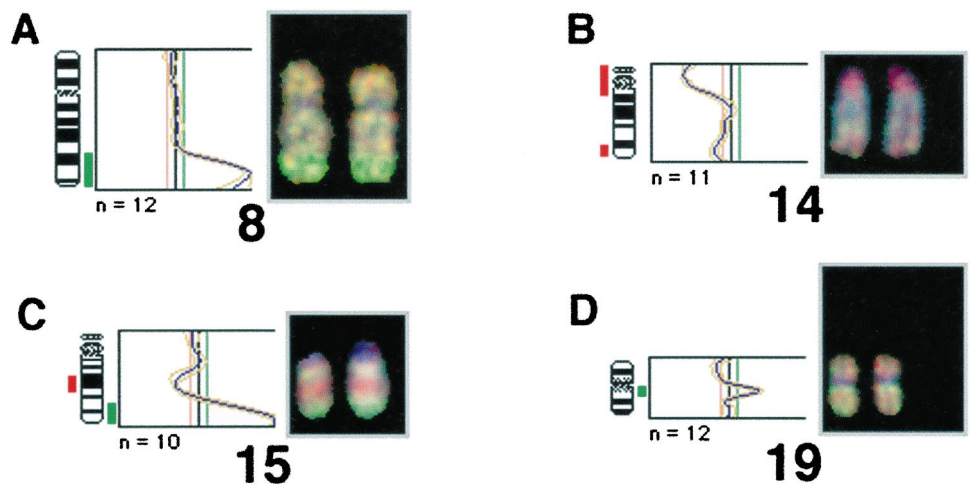


Fig. 2. CGH of four GEJ adenocarcinomas illustrating specific frequent deletions or high-level amplifications. The chromosomal ideograms are shown along with the ratio profiles and the digitized fluorescent images. A, high-level amplification of 8qter (MYC region) in an adenocarcinoma of the junction (ba11; nonclassifiable). B, deletion of 14q31–32.1 in an esophageal tumor cell line (oe33). C, amplification of 15qter, including 15q25, in a gastric cardia cancer (xenograft m2.1); also, a deletion is present, proximal from the amplification. D, high-level amplification of 19q13.1 (ba15; cardia carcinoma).





and the distribution of the chromosomal alterations, is clearly different from other frequently occurring human solid tumors, such as cancers of the breast, lung, or prostate (reviewed in Refs. 39 and 40). A number of new, not previously documented, genetic changes were detected (e.g., loss on 14q and 16q, or gain of 5p and 13q). Other aberrations were confirmed, such as loss on 4pq, 5q, and 18q, or gain of 20pq and 8q. New high-level amplifications are reported (i.e., on 15q25 and 19q13.1), and minimal regions were determined at several chromosomal sites. Furthermore, genetic divergence within GEJ adenocarcinomas was disclosed. Below, we will discuss the most prevalent and/or relevant alterations, as well as candidate genes (Tumor suppressor and oncogenes described below are reviewed in Refs. 41–43).

**Chromosomal Losses.** The most frequent loss seemed to involve chromosome 4, the long arm slightly more than the short arm. This is in agreement with previous molecular studies in which frequent LOH on 4q was found (27). So, far, no genes have been implicated for the deletion in this region.

About 50% of the neoplasms exhibited loss on 14q with a minimal region at 14q31–32.1. This region is clearly different from the 14q loss that is frequently encountered in gastrointestinal stromal tumors (i.e., 14q22; Ref. 44). A possible candidate gene residing in our chromosomal region is the *TSHR*, a gene involved in adenocarcinomas of the thyroid gland. Interestingly, this deletion points at genetic divergence in GEJ cancers: Frequent loss (64%) was seen in Barrett-related esophageal adenocarcinomas, but not in gastric cardia tumors (10%;  $P = 0.02$ ). This might be associated with different cancer stem cells in Barrett's transformed esophageal mucosa, a condition not known in the proximal stomach. The "unclassified" group displayed an intermediate status (43% loss), which is possibly related to the presence of a so-called short-segment Barrett's esophagus (6).

The loss encountered on 3p14 (21% of the tumors) seems to involve the *FHIT* gene. Recently, frequent deletions of *FHIT* were reported in Barrett's esophagus and adenocarcinoma (45). Some of the deleted areas could be connected with known tumor suppressor genes, such as *MCC* (5q21), *MTS1* (9p21), or *DCC* (18q21), whereas other regions might harbor yet unknown suppressor genes (i.e., 16q23 and 21q21). We found loss on 17p in ~30% of the cancers. LOH of the p53 region has been reported in varying frequencies in esophageal adenocarcinoma (26, 27).

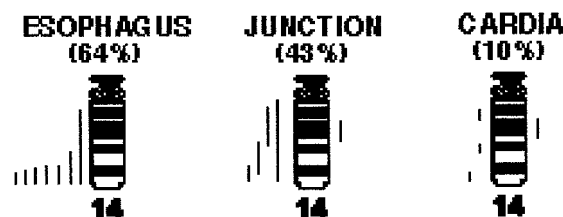


Fig. 3. Chromosome 14 ideograms demonstrating the prevalence of distal 14q deletions (14q31–32.1) in the three GEJ groups. Note frequent loss in Barrett-related esophageal adenocarcinomas, in contrast to gastric cardia tumors ( $P = 0.02$ ). The unclassified junction tumors display an intermediate position.

**Chromosomal Gains.** The most frequent gain occurred at chromosome 20 (86% of all tumors), the long arm (20q12–13) being slightly more altered than the short arm (20p12). The latter gain might involve *PCNA*. Loss of 20q has been reported in various solid cancers and was found associated with a poor prognosis in breast cancer (46). Several candidate genes have been suggested, among them *MYBL2* or *PTPN1*, a nonreceptor tyrosine phosphatase involved in growth regulation (47).

Numerous gain (79%) was also seen of the long arm of chromosome 8 (see also "Amplifications"). Gain of 8q, often involving the whole chromosome arm, is seen in many human cancers (e.g., prostate cancer; Ref. 40). Other chromosomal areas, frequently gained, were 5p14, 6p12–21.1, 7p12, 12q21.1, and Xq25. The gain of 7p12 is likely to be associated with the *EGFR*, a gene often involved in human neoplasms. The gain of 5p14 might implicate a leukemia virus integration site (*MLV12*), and 6p gain is possibly related to *NRASL3*, which belongs to the *RAS* superfamily (47).

**Amplifications.** A distinction is made between gains and amplifications, as pointed out recently by Knuttila *et al.* (47). True amplifications, likely representing chromosomal amplicons, are seen as a distinct and high peak in the CGH profile of a given neoplasm. However, there is a gray area between gain and amplification, which is clearly illustrated in our series by the 7p12 region (*EGFR*). This site showed frequent and specific gain, but no high-level amplification. We observed amplifications (>10% of all tumors) for the following chromosomal regions: 8q23–24.1, 15q25, 17q12–21, and 19q13.1. The 8q and 17q amplicons are likely to be associated with, respectively, *MYC* and *ERBB2*, oncogenes frequently involved in various cancers. However, the amplifications at 15q and 19q, possibly characteristic for GEJ adenocarcinomas, are not easily attributed to a candidate gene because they have not been described before as putative oncogenic sites.

The 15qter amplification might implicate the *IGF1R* gene, which has been reported to be sporadically amplified in human breast cancer, in some cases with coamplification of *FES*, residing at 15q26.1. (48). The amplification at 19q31.1 could be associated with *TGFβ*, *BCL3*, or *AKT2*, a murine thymoma oncogene homologue (Table 2). However, further investigation is needed to elucidate the nature of the chromosome 15 and 19 amplifications, which might play an important role in GEJ cancers.

In conclusion, this study has revealed a variety of chromosomal aberrations in GEJ cancers. Some of these changes might be found in all types of cancer, whereas others might be associated with epithelial neoplasms. The genomic patterns of the three GEJ tumor types, revealed by CGH, are markedly similar, indicating that they are a closely related entity. However, one genetic change (del14q) was distinguished that varied between the three groups, suggesting some degree of tissue specificity. Presently, we are further investigating this region by LOH analysis.<sup>4</sup> Overall, the CGH profile of

Table 2. List of genes, potentially involved in frequent alterations (amp,<sup>a</sup> del) of adenocarcinomas of the GEJ

CGH aberration	Candidate gene	Location	Function
3p14 del	<i>FHIT</i>	3p14.2	Suppression
	<i>RCA1</i>	3p14.2	Suppression
5p14 amp	<i>MLV12</i>	5p14	Activation (?)
5q14-21 del	<i>MCC</i>	5q21	Suppression
	<i>APC</i>	5q21-22	Suppression
6p12-21.1 amp	<i>NRASL3</i>	6p12-ter	Activation
7p12 amp	<i>EGFR</i>	7p12	Activation
8q23-24.1 amp	<i>MYC</i>	8q24.1	Activation
9p21 del	<i>MTS1</i>	9p21	Suppression
14q31-32.1 del	<i>TSHR</i>	14q31	Suppression
15q25 amp	<i>IGF1R</i>	15q25-26	Activation (?)
17q12-21 amp	<i>HER2-neu</i>	17q12-21	Activation
	<i>ERBB2</i>		
18q21 del	<i>DCC</i>	18q21.3	Suppression
	<i>P15</i>	18q21.3	Suppression
19q13.1 amp	<i>TGFβ1</i>	19q13	Activation
	<i>BCL3</i>	19q13	Activation
	<i>AKT2</i>	19q13	Activation
	<i>PCNA</i>	20p12	Activation (?)
20p12 amp	<i>MYBL2</i>	20q13.1	Activation
20q12-13 amp	<i>PTPN1</i>	20q13	Activation (?)

<sup>a</sup> amp, gain/amplification; del, deletion; *RCA1*, renal carcinoma, familial-associated 1; *HER2-neu*, V-erb-b2; *P15*, protease inhibitor 5 (maspin).

<sup>4</sup> B. P. L. Wijnhoven, unpublished data.

GEJ cancer is clearly different from other malignancies. Therefore, the deletion of 14q31–32.1 or the amplifications at 15q25 and 19q13.1, might have diagnostic use for adenocarcinomas of the GEJ.

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## REFERENCES

- Blot, W. J., Devesa, S. S., Kneller, R. W., and Fraumeni, J. F., Jr. Rising incidence of adenocarcinoma of the esophagus and gastric cardia. *J. Am. Med. Assoc.*, 265: 1287–1289, 1991.
- Powell, J., and McConkey, C. C. The rising trend in esophageal adenocarcinoma and gastric cardia. *Eur. J. Cancer Prev.*, 1: 265–269, 1992.
- Spechler, S. J., and Goyal, R. K. Barrett's esophagus. *N. Engl. J. Med.*, 315: 362–371, 1986.
- Cameron, A. J., and Lomboy, C. T. Barrett's esophagus: age, prevalence and extent of columnar epithelium. *Gastroenterology*, 103: 1241–1245, 1992.
- Haggitt, R. C. Barrett's esophagus, dysplasia and adenocarcinoma. *Hum. Pathol.*, 25: 982–993, 1994.
- Spechler, S. J., Zeroogian, J. M., Antonioli, J. A., Wang, H. H., and Goyal, R. K. Prevalence of metaplasia at the gastro-esophageal junction. *Lancet*, 344: 1533–1536, 1994.
- Morales, T. G., Sampliner, R. E., and Bhattacharyya, A. Intestinal metaplasia of the gastric cardia. *Am. J. Gastroenterol.*, 92: 414–418, 1997.
- Menke-Pluymers, M. B. E., Schoute, N. W., Mulder, A. H., Hop, W. C. J., van Blankenstein, M., and Tilanus, H. W. Outcome of surgical treatment of adenocarcinoma in Barrett's esophagus. *Gut*, 33: 1454–1458, 1992.
- Blomjous, J. G., Hop, W. C. J., Langenhorst, B. L., ten Kate, F. L., Eykenboom, W. M., and Tilanus, H. W. Adenocarcinoma of the gastric cardia: recurrence and survival after resection. *Cancer (Phila.)*, 70: 569–574, 1992.
- Blot, W. J., Devesa, S. S., Fraumeni, J. F., Jr. Re: "Continuing climb in rates of esophageal adenocarcinoma" (Letter). *J. Am. Med. Assoc.*, 270: 1320, 1993.
- Pera, M., Cameron, A. J., Trastek, V. F., Carpenter, H. A., and Zinsmeister, H. R. Increasing incidence of adenocarcinoma of the esophagus and esophagogastric junction. *Gastroenterology*, 104: 510–513, 1993.
- Locke, G. R., III, Talley, N. J., Carpenter, H. A., Harmsen, W. S., Zinsmeister, H. R., and Melton, L. J., III. Changes in the site- and histology-specific incidence of gastric cancer during a 50-year period. *Gastroenterology*, 109: 1750–1756, 1995.
- Chow, W. H., Finkle, W. D., McLaughlin, J. K., Frankl, H., Ziel, H. K., and Fraumeni, J. F., Jr. The relation of gastroesophageal reflux disease and its treatment to adenocarcinomas of the esophagus and gastric cardia. *J. Am. Med. Assoc.*, 274: 474–477, 1995.
- Gammon, M. D., Schoenberg, J. B., Ahsan, H., Risch, H. A., Vaughan, T. L., Chow, W. H., Rotterdam, H., West, H. B., Dubrow, H. R., Stanford, J. L., Mayne, S. T., Farrow, D. C., Niwa, S., Blot, W. J., and Fraumeni, J. F., Jr. Tobacco, alcohol, and socioeconomic status and adenocarcinoma of the esophagus and gastric cardia. *J. Natl. Cancer Inst.*, 89: 1277–1284, 1997.
- Kabat, G. C., Ng, S. K., and Wynder, E. L. Tobacco, alcohol intake, and diet in relation to adenocarcinoma of the esophagus and gastric cardia. *Cancer Causes Control*, 4: 123–132, 1993.
- Zhang, Z. F., Kurtz, R. C., Yu, G. P., Sun, M. P., Gargon, R., Karpeh, M., Jr., Fein, J. S., and Harlap, S. Adenocarcinoma of the esophagus and gastric cardia: the role of diet. *Nutr. Cancer*, 27: 298–309, 1997.
- Chow, W. H., Blot, W. J., Vaughan, T. L., Risch, H. A., Gammon, M. D., Stanford, J. L., Dubrow, R., Schoenberg, J. B., Mayne, S. T., Farrow, D. C., Ahsan, H., West, A. B., Rotterdam, H., and Fraumeni, J. F., Jr. Body mass index and risk of adenocarcinomas of the esophagus and gastric cardia. *J. Natl. Cancer Inst.*, 21: 150–155, 1998.
- Rodriguez, E., Rao, P. H., Ladanyi, M., Altorki, N., Albino, A. P., Kelsen, D. P., Jhanwar, S. C., and Chaganti, R. S. K. 11p13–15 is a specific region of chromosomal rearrangement in gastric and esophageal adenocarcinomas. *Cancer Res.*, 50: 6410–6416, 1990.
- Rao, P. H., Mathew, S., Kelsen, D. P., and Chaganti, R. S. K. Cytogenetics of gastric and esophageal adenocarcinomas. 3q Deletion as a possible primary chromosomal change. *Cancer Genet. Cytogenet.*, 81: 139–143, 1995.
- Menke-Pluymers, M. B. E., van Drunen, E., Vissers, K. J., Mulder, A. H., Tilanus, H. W., and Hagemier-Hausman, A. M. M. J. Cytogenetic analysis of Barrett's mucosa and adenocarcinoma of the distal esophagus and cardia. *Cancer Genet. Cytogenet.*, 90: 109–117, 1996.
- Houldsworth, J., Cordon-Cardo, C., Ladanyi, M., Kelsen, D. P., and Chaganti, R. S. K. Gene amplification in gastric and esophageal adenocarcinomas. *Cancer Res.*, 50: 6417–6422, 1990.
- Ranzani, G. N., Renault, B., Pellegata, N. S., Fattorini, P., Magni, E., Bacci, F., and Amadori, D. Loss of heterozygosity and K-ras gene mutations in gastric cancer. *Hum. Genet.*, 92: 244–249, 1993.
- Tamura, G., Maesawa, C., Suzuki, Y., Ogasawara, S., Terashima, M., Saito, K., and Satodate, R. Primary gastric carcinoma cells frequently lose heterozygosity at the APC and MCC genetic loci. *Jpn. J. Cancer Res.*, 84: 1015–1018, 1993.
- Gleeson, C. M., Sloan, J. M., McGuigan, J. A., Ritchie, A. J., Weber, J. L., and Russell, S. E. Allelotype analysis of adenocarcinoma of the gastric cardia. *Br. J. Cancer*, 76: 1455–1465, 1997.
- Blount, P. L., Meltzer, S. J., Yin, J., Huang, Y., Krasna, M. J., and Reid, B. J. Clonal ordering of 17p and 5q allelic losses in Barrett's dysplasia and adenocarcinoma. *Proc. Natl. Acad. Sci. USA*, 90: 3221–3225, 1993.
- Barrett, M. T., Galipeau, P. C., Sanchez, C. A., Emond, M. J., and Reid, B. J. Determination of the frequency of loss of heterozygosity in esophageal adenocarcinoma by cell sorting, whole genome amplification and microsatellite polymorphisms. *Oncogene*, 12: 1873–1878, 1996.
- Hammoud, Z. T., Kaleem, Z., Cooper, J. D., Sundaresan, R. S., Patterson, G. A., and Goodfellow, P. J. Allelotype analysis of esophageal adenocarcinomas: evidence for the involvement of sequences on the long arm of chromosome 4. *Cancer Res.*, 56: 4499–4502, 1996.
- Gleeson, C. M., Sloan, J. M., McGuigan, J. A., Ritchie, A. J., Weber, J. L., and Russell, S. E. Barrett's esophagus: microsatellite analysis provides evidence to support the proposed metaplasia-dysplasia-carcinoma sequence. *Genes Chromosomes Cancer*, 21: 49–60, 1998.
- Van Dekken, H., Pizzolo, J., Kelsen, D. P., and Melamed, M. R. Targeted cytogenetic analysis of gastric tumors by *in situ* hybridization with a set of chromosome-specific DNA probes. *Cancer (Phila.)*, 66: 491–497, 1990.
- Hunter, S., Gramlich, T., Abbott, K., and Varma, V. Y. Chromosome loss in esophageal carcinoma: an *in situ* hybridization study. *Genes Chromosomes Cancer*, 8: 172–177, 1993.
- Krishnadath, K. K., Tilanus, H. W., Alers, J. C., Mulder, A. H., and van Dekken, H. Detection of genetic changes in Barrett's adenocarcinoma and Barrett's esophagus by DNA *in situ* hybridization and immunohistochemistry. *Cytometry*, 15: 176–184, 1994.
- Krishnadath, K. K., Tilanus, H. W., van Blankenstein, M., Hop, W. C. J., Teijgeman, R., Mulder, A. H., Bosman, F. T., and van Dekken, H. Accumulation of genetic abnormalities during neoplastic progression in Barrett's esophagus. *Cancer Res.*, 55: 1971–1976, 1995.
- El-Rifai, W., Harper, J. C., Cummings, O. W., Hyttinen, E. R., Frierson, H. F., Jr., Knuutila, S., and Powell, S. M. Consistent genetic alterations in xenografts of proximal stomach and gastro-esophageal junction adenocarcinomas. *Cancer Res.*, 58: 34–37, 1998.
- Moskaluk, C. A., Hu, J., and Perlman, P. J. Comparative genomic hybridization of esophageal and gastroesophageal adenocarcinomas shows consensus areas of DNA gain and loss. *Genes Chromosomes Cancer*, 22: 305–311, 1998.
- Rockett, J. C., Larkin, K., Darnton, S. J., Morris, A. G., and Matthews, H. R. Five newly established oesophageal carcinoma cell lines: phenotypic and immunological characterization. *Br. J. Cancer*, 75: 258–263, 1997.
- Spiessl, B., Beahrs, O. H., Hermanek, P., Hutter, R. V. P., Scheibe, O., Sobin, L. H., and Wagner, G. TNM Atlas International Union Against Cancer/Union Internationale Contre le Cancer (UICC), pp. 62–81. Heidelberg: Springer-Verlag, 1992.
- Kallioniemi, A., Kallioniemi, O.-P., Sudar, D., Rutovitz, D., Gray, J. W., Waldman, F., and Pinkel, D. Comparative genomic hybridization for molecular cytogenetic analysis of solid tumors. *Science (Washington DC)*, 258: 818–821, 1992.
- Rosenberg, C., Schut, T. B., Mostert, M. C., Tanke, H. J., Raap, A. K., Oosterhuis, J. W., and Looijenga, L. H. Comparative genomic hybridization in hypodiploid/hypertriploid tumors. *Cytometry*, 29: 113–121, 1997.
- Alers, J. C., and van Dekken, H. Interphase cytogenetic analysis of solid tumors by non-isotopic DNA *in situ* hybridization (Review). *Prog. Histochem. Cytochem.*, 31: 1–137, 1996.
- Van Dekken, H., Rosenberg, C., Krijtenburg, P. J., and Alers, J. C. Interphase cytogenetics and comparative genomic hybridization of human epithelial cancers and precursor lesions (Review). *Histochem. Cell Biol.*, 108: 419–430, 1997.
- Sidransky, D. Nucleic acid-based methods for the detection of cancer (Review). *Science (Washington DC)*, 278: 1054–1059, 1997.
- Schwab, M. Amplification of oncogenes in human cancer cells (Review). *Bioessays*, 20: 473–479, 1998.
- Pearson, P. L., and van der Luijt, R. B. The genetic analysis of cancer (Review). *J. Intern. Med.*, 243: 413–417, 1998.
- El-Rifai, W., Sarlomo-Rikala, M., Miettinen, M., Knuutila, S., and Andersson, L. C. DNA copy number losses in chromosome 14: an early change in gastrointestinal stromal tumors. *Cancer Res.*, 56: 3230–3233, 1996.
- Michael, D., Beer, D. G., Wilke, C. W., Miller, D. E., and Glover, T. E. Frequent deletions of FHIT and FRA3B in Barrett's metaplasia and esophageal adenocarcinoma. *Oncogene*, 15: 1653–1659, 1997.
- Tanner, M. M., Tirkkonen, M., Kallioniemi, A., Isola, J., Kuukasjärvi, T., Collins, C., Kowbel, D., Guan, X. Y., Trent, J., Gray, J. W., Meltzer, P., and Kallioniemi, O.-P. Independent amplification and frequent co-amplification of three nonsyntenic regions on the long arm of chromosome 20 in human breast cancer. *Cancer Res.*, 56: 3441–3445, 1996.
- Knuutila, S., Björkqvist, A.-M., Autio, K., Tarkkanen, M., Wolf, M., Monni, O., Szymanska, J., Larramendy, M. L., Tapper, J., Pere, H., El-Rifai, W., Hemmer, S., Wasenius, V.-M., Vidgreb, V., and Zhu, Y. DNA copy number amplifications in human neoplasms: review of comparative genomic hybridization studies. *Am. J. Pathol.*, 152: 1107–1123, 1998.
- Berns, E. M. J., Kljij, J. G. M., van Staveren, L. I., Portengen, H., and Foekens, J. A. Sporadic amplification of the insulin-like growth factor 1 receptor gene in human breast tumors. *Cancer Res.*, 52: 1036–1039, 1992.

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## Comparative Genomic Hybridization of Cancer of the Gastroesophageal Junction: Deletion of 14Q31–32.1 Discriminates between Esophageal (Barrett's) and Gastric Cardia Adenocarcinomas

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