

X

DNA

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X DNA (Ta)
 pGEM-3Zf(-) plasmid DNA (monolayer) , 가 1.5 keV K X 0 , 3 , 7 ,
 10 DNA (mean absorbed dose) DNA
 . 3 eV X . X
 plasmid DNA (electrophoresis) supercoiled DNAsupercoiled DNA
 . Supercoiled DNA X eV 가
 . circular DNA crosslinked form 1 DNA 가 가 .
 supercoiled DNA가 가 (single strand break)
 unsupercoiled DNA X DNA
 , DNA (0~10 eV) DNA
 .
 : DNA , , X , ,

1. [3].
 X DNA , 2 가
 , 가 1 MeV 20 eV
 (single strand breaks: SSBs), 가 (double DNA 5x10 가 .
 strand breaks: DSBs) DNA (dissociative electron attachment: DEA)
 [1-3]. DNA . DEA ,
 가 DNA
 DNA DNA 가 DNA
 , , 2 DEA AB .
 (radical), , ,
 2 (secondary species) DNA
 [4-6]. 19 $AB + e^- \rightarrow AB^{-(*)} \rightarrow A^{(*)} + B^{-(*)}$.
 . DNA
 2 DNA가 Sanche DNA
 가 가 Sanche plasmid DNA , oligonucleotide
 DNA
 DNA
 DNA
 DNA
 DNA [7-14].

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X 가 1.5 keV Al K .
 (fragments) X , X
 [4,15,16]. plasmid DNA X (main chamber) plasmid DNA (sample loading chamber) .
 가 100 eV , , , . ~10⁻¹⁰ torr 24
 20 eV . ~10⁻⁹ torr (gate)
 X DNA (differential pumping) linear feedthrough가
 , 10 eV 2 , X plasmid DNA 16 X X
 plasmid DNA 가 DNA plasmid DNA . X X
 Keithley 610C solid-state electrometer
 2. 0.78 nA (flux) 2.49 × 10⁹ electrons cm⁻² s⁻¹
 pGEM-3Zf(-) plasmid DNA(3197 bp) coli M109
 QIAfilter Plasmid Giga [17-20].
 Kit(Qiagen) . 1% 가 plasmid DNA
 plasmid DNA 95% supercoiled DNA plasmid DNA
 5% unsupercoiled DNA . X (hatch)
 , plasmid DNA 3 ,
 DNA linear feedthrough
 가
 Plasmid DNA plasmid DNA 10 ,
 가 (Faraday cup) phosphor screen
 가 0.025 mm X phosphor screen
 가 25 × 7 mm ,
 가 14 × 14 mm . plasmid DNA (= 5.1 mm)
 plasmid DNA μ15 TE 60 ng
 plasmid DNA가 . plasmid DNA 1.4 nA 3 eV
 4.29 × 10¹⁰ electrons cm⁻² s⁻¹ .
 DNA 15 μl plasmid 24
 5 -40 10⁻¹⁰ torr . plasmid DNA
 (sorption pump) 1~2 plasmid DNA 0 3 , 7 , 10 3 XeV
 plasmid DNA (monolayer) plasmid DNA X
 2 nm 5.1 ± 0.2 mm 1.4 g/cm (1) (mean absorbed dose)
 plasmid DNA X
 가 ~10⁻¹⁰ torr

$$D_m = N_{tot} E_{ek} C_E / M_{DNA} \quad (1)$$
 X PHI Model 04-548 Dual Anode ;
 Source(Perkin-Elmer) , , N_{tot} , E_{ek} , C_E
 4 kV, 1.1 mA . 1.6 × 10⁻¹⁹ J eV⁻¹ M_{DNA} DNA

70 Gys
 X 4.056 Gyjs
 X 가 ddH₂O 121
 plasmid DNA DNA
 가 DNA 260 nm UV
 spectrophotometer(Hitachi U-2000) UV 98%
 가 가 DNA
 DNA μl (6x) 2 μl
 SYBR GREEN (100x) 가 15 . 1kb
 DNA Marker DNA TAE (40 mM
 acetate, 1 mM EDTA, pH 8.0)가 1% 가
 7 100 V, 68 75 V
 (450 nm)
 STORM860 (Molecular Dynamics)
 Plasmid DNA ImageQuant (Molecular
 Dynamics)

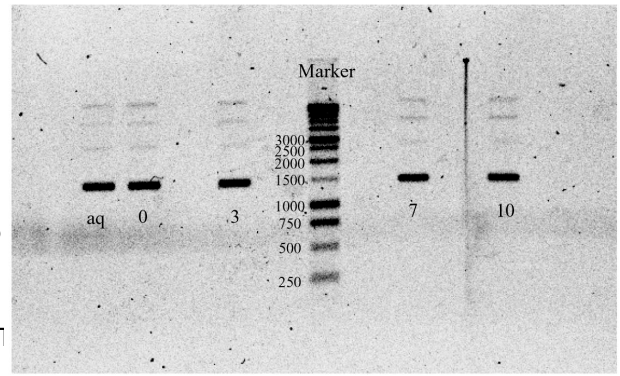


Fig. 2. Agarose gel electrophoresis of pGEM-3Zf(-) plasmid DNA irradiated by 3 eV electron beam for various times. The bands starting from the top are crosslinked form 1, circular, concatemeric and supercoiled DNA, respectively.

3. aqueous DNA supercoiled DNA 93.507%
 unsupercoiled DNA 6.493% Unsupercoiled DNA
 가 circular DNA가 가
 1 Al K X 0 , 가
 3 , 7 , 10 1% 가 3.754% 10 9.374% 2.5 가
 pGEM-3Zf(-) plasmid DNA crosslinked form 1 1.660%
 1 (lane) DNA marker, aqueous 3.342% 2.5 가 circular DNA
 DNA, 0 , 3 , 7 , 10가
 X 2 3 eV
 DNA marker 0 , 3 , 7 , 10 1% 가
 supercoiled(S), concatemeric(CM), circular(C),
 crosslinked form 1(CL1) DNA . Aqueous DNA 2 pGEM-3Zf(-) plasmid DNA
 X , 3 , DNA marker, 7 10 aqueous DNA, 0
 DNA supercoiled DNA unsupercoiled 1 가 DNA marker
 DNA aqueous DNA supercoiled(S), concatemeric(CM), circular(C),
 crosslinked form 1(CL1) DNA . X
 가 unsupercoiled DNA 가
 circular DNA가 가 가

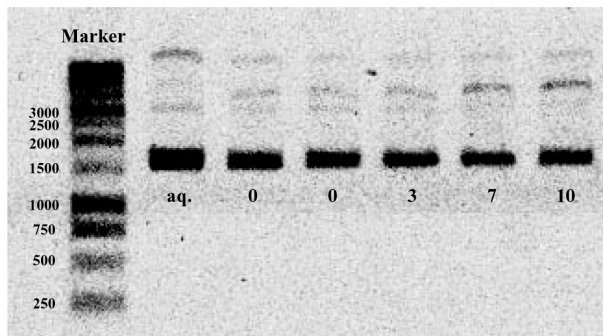


Fig. 1. Agarose gel electrophoresis of pGEM-3Zf(-) plasmid DNA irradiated by Al K α X-rays for various times. The bands starting from the top are crosslinked form 1, circular, concatemeric and supercoiled DNA, respectively.

aqueous DNA supercoiled DNA가 91.738%
 unsupercoiled DNA 8.262% . X
 2%
 X
 93.500% 가
 3 1 X DNA
 ImageQuant
 DNA
 5.0(Molecular dynamics)
 3 (a)-(c) X
 supercoiled DNA, crosslinked form 1 DNA, circular DNA
 , (d)-(f) supercoiled DNA,
 crosslinked form 1 DNA, circular DNA . 3
 (linear fitting)
 X DNA 98% X

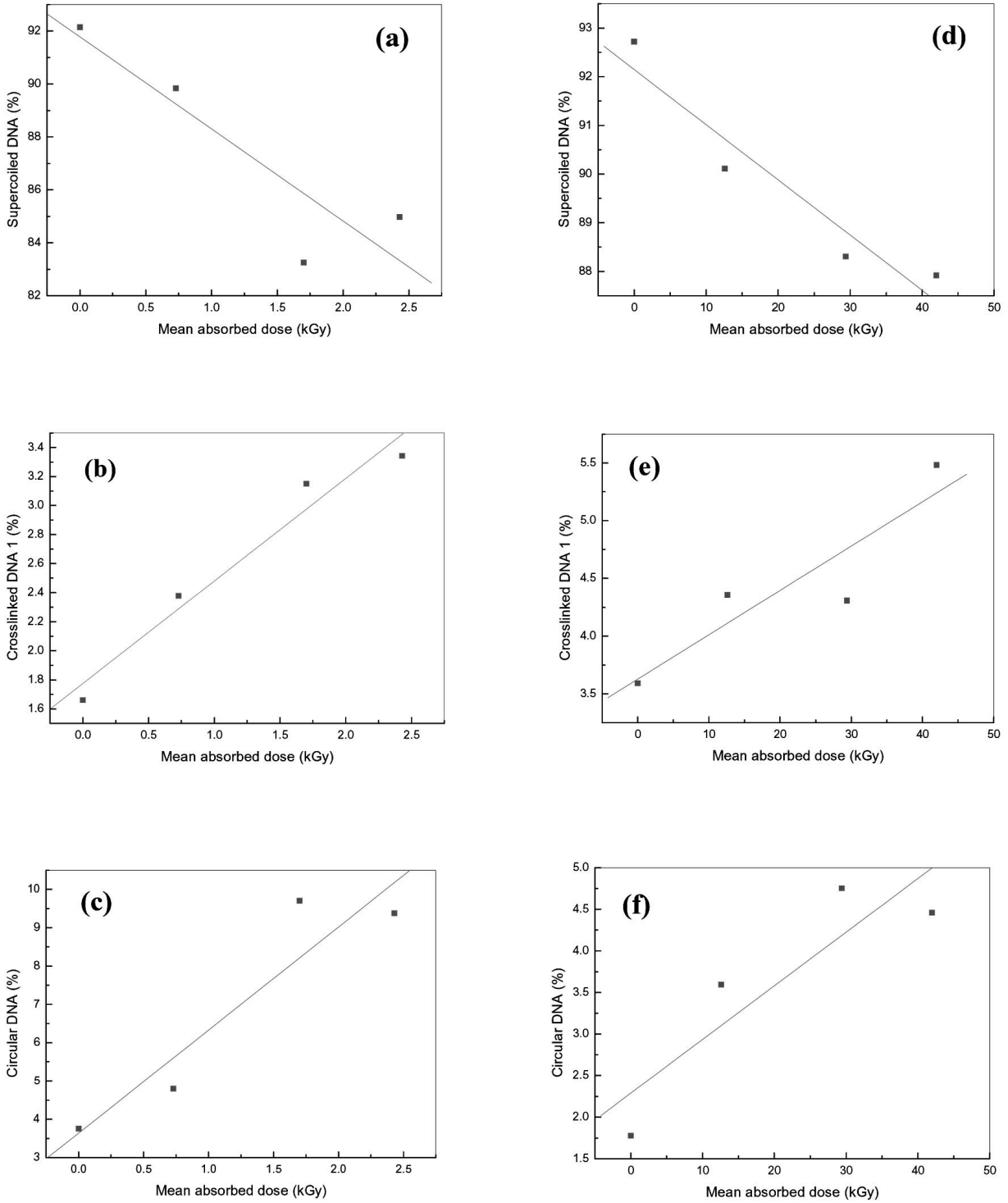


Fig. 3. X-ray exposure curves for the loss of (a) supercoiled as well as the formation of (b) crosslinked form 1, (c) circular DNA and electron beam exposure curves for the loss of (d) supercoiled as well as the formation of (e) crosslinked form 1, (f) circular DNA were irradiated in monolayer DNA film.

(multi) (10 eV)
 2% X
 (photon) .
 DNA X DNA 10 eV 가

Table 1. The Specific Yields for Each DNA Form. S: supercoiled DNA, C: circular DNA, CL1: crosslinked form 1 DNA, CM: concatemeric DNA.

Irradiation time		aq.	0 min	3 min	7 min	10 min
X-ray Irradiation	S	93.507%	92.114%	89.838%	83.255%	84.975%
	C	1.190%	3.754%	4.779%	9.670%	9.374%
	CL1	13.321%	1.660%	2.378%	3.150%	3.342%
	CM	1.982%	2.441%	2.985%	3.925%	2.309%
Electron Irradiation	S	91.738%	92.720%	90.112%	88.304%	87.919%
	C	2.463%	1.776%	3.594%	4.753%	4.458%
	CL1	13.198%	3.592%	4.356%	4.307%	5.482%
	CM	2.612%	1.912%	1.928%	2.637%	2.141%

Zhongli Cai et al. X-ray photoelectron spectrometer(XPS, Perkin-Elmer) [17].
 (0~1486 eV) 1.4 eV, 5.8 eV, 10 eV
 3 eV DNA DNA
 3 eV DNA DNA
 3 eV DNA DNA
 Panajotovic et al. pGEM-3Zf(-) plasmid DNA 0.1~4.7 eV 10 eV X
 가 supercoiled DNA
 (effective cross section: ECS) [18].
 (0.1 ~ 4.7 eV) 가 DNA
 가 3.1 eV ECS 0 ~ 2.5 kGy supercoiled DNA 9%
 = $(12.3 \pm 1.0) \times 10^{-15} \text{ cm}^2$, 1 eV
 = $(24.8 \pm 0.2) \times 10^{-15} \text{ cm}^2$, 1 eV 0 ~ 40 kGy supercoiled DNA 5%
 3.1 eV ECS 가 2 X (scale) 2.5 kGy
 3 supercoiled DNA 3
 eV DNA
 1.4 eV 가 Circular DNA
 DNA 2 crosslinked DNA 1 가
 Zhongli Cai et al. X X Circular DNA 가
 DNA 가 DNA 3 (c), (f)
 가 DNA , 3 eV circular DNA 5%
 [17].
 Panajotovic et al. DNA 가 ECS 3 eV DNA
 DNA %가 circular DNA
 %가 linear DNA [18].
 DNA X DNA DEA
 DNA [2,5]. 가 R. Barrios et al.
 , 10 eV , DNA
 가 DNA
 3 eV , 1 eV π^*

(temporary negative ion; TNI)
 (anion) - X 0~20 eV DNA DNA (DNA)
 C-O 가 DNA complex)
 3 eV DNA
 10 eV 가 DNA
 DNA
 DNA
 가 가
 DNA DNA
 DNA (sugar)
 DNA
 DNA
 DEA DNA
 9 eV (charge THF)
 tetrahydrofuran(THF) trapping cross section) 가 1 eV
 $\sigma_{CT} = 3.83 \times 10^{-17} \text{ cm}^2$
 4.
 plasmid DNA pGEM-3Zf(-)
 keV 0, 3, 7, 10 Al K X-ray (1.5
 DNA
 가 가 supercoiled DNA
 , circular, crosslinked
 form 1 DNA unsupercoiled DNA
 supercoiled DNA 가
 Supercoiled DNA 가 X
 (10 eV)
 3 eV , 3 eV
 DNA 가 가
 X
 10 eV
 DNA 3 eV 가
 가
 DNA
 DNA
 DNA
 DEA , 가 DNA
 가 DNA
 π^* TNI π^*
 (anion) - C-O 가
 π^* C-O 가
 DNA
 , DNA DNA
 (0~10 eV) DNA

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DNA Damage by X-ray and Low Energy Electron Beam Irradiation

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Abstract - We observed DNA damages as a function of mean absorbed dose to identify the indirect effect of high-energy radiation such as x-ray. Monolayer films of lyophilized pGEM-3Zf(-) plasmid DNA deposited on tantalum foils were exposed to Al K X-ray (1.5 keV) for 0, 3, 7 and 10 min, respectively, in a condition of ultrahigh vacuum state. We compared DNA damages by X-ray irradiation with those by 3 eV electron irradiation. X-ray photons produced low-energy electrons (mainly below 20 eV) from the tantalum foils and DNA damage was induced chiefly by these electrons. For electron beam irradiation, DNA damage was directly caused by 3 eV electrons. Irradiated DNA was analyzed by agarose gel electrophoresis and quantified by ImagaQuant program. The quantities of remained supercoiled DNA after irradiation were linearly decreased as a function of mean absorbed dose. On the other hand, the yields of nicked circular (single strand break, SSB) and interduplex crosslinked form I DNA were linearly increased as a function of mean absorbed dose. From this study, it was confirmed that DNA damage was also induced by low energy electrons (0~10 eV) even below threshold energies for the ionization of DNA.

Keywords : DNA damage, Indirect action, X-ray, Low-energy electron beam, Dissociative electron attachment.