Communication and sampling rate limitations in IMRT delivery with a dynamic multileaf collimator system

Ping Xia,[a] Cynthia F. Chuang, and Lynn J. Verhey
The Department of Radiation Oncology, University of California at San Francisco, San Francisco, California 94143

(Received 13 July 2001; accepted for publication 4 December 2001; published 21 February 2002)

The delivery of an intensity modulated radiation field with a dynamic multileaf collimator (MLC) requires precise correlation between MLC positions and cumulative monitor units (MUs). The purpose of this study is to investigate the precision of this correlation as a function of delivered MUs and dose rate. A semi-Gaussian shaped intensity profile and a simple geometric intensity pattern consisting of four square segments were designed to deliver a total of 1, 4, 16, 64, and 100 MUs at three different dose rates of 100, 400, and 600 MU/min. The semi-Gaussian intensity pattern was delivered using both sliding window and step and shoot techniques. The dose profiles of this intensity pattern were measured with films. The four square intensity pattern was delivered using step and shoot and conventional delivery techniques for comparison. Because of geometrical symmetry, the dose to each segment in this intensity pattern is expected to be the same when the same MU is assigned to each segment. An ionization chamber was used to measure the dose in the center of each of the four square segments. For the semi-Gaussian shaped profile, significant artifacts were observed when the profile was delivered with small MUs and/or at a high dose rate. For the four square intensity pattern, the dose measured in each segment presented a large variation when delivered with small MUs and a high dose rate. The variation increases as the MU/segment decreases and as the dose rate increases. These MU and dose rate dependencies were not observed when the intensity pattern was delivered using a conventional delivery technique. The observed distortion of the semi-Gaussian profile and dose variations among the segments of the four square intensity pattern are explained by considering the sampling rate and the communication time lag between the control systems. Finally, clinical significance is discussed. [DOI: 10.1118/1.1449496]

Key words: intensity modulated radiotherapy, dynamic multileaf collimator, step and shoot

I. INTRODUCTION

Computer controlled multileaf collimator (MLC) systems have made intensity modulated radiation therapy (IMRT) clinically practical, using either dynamic or static delivery techniques.[1–10] The fundamental difference between these two delivery methodologies is that with dynamic delivery, the radiation and the MLC leaf motions can be executed simultaneously,[2–5,7] whereas with static delivery, the radiation and leaf motions are executed sequentially.[6,8–10] The latter delivery method resembles conventional delivery, except that many segments are included in each given field. Due to the use of many small sized segments with associated small monitor units (MUs), the dose accuracy of static delivery can be affected by the accuracy of leaf positioning, and by dose nonlinearity for small MU delivery.

In dynamic delivery, the key factors that affect dose accuracy include the accuracy of the leaf positions and the correlation between the leaf positions and the accumulated dose, similar to the situation of the dynamic wedge.[11] Unlike the dynamic wedge, in which only one pair of jaws is used, the dynamic MLC-IMRT delivery employs many pairs of MLC leaves, and each has a different intensity profile. In order to let all leaves move to their designated positions,

needed for implementation of dynamic MLC-IMRT delivery. In leaf speed modulation, the leaf speed for each pair of MLC leaves is different, but constant within each segment. In dose rate modulation, a maximum dose rate is used whenever it is possible to achieve efficient delivery, but when the required leaf speed exceeds the maximum mechanical leaf speed, the dose rate is reduced.

A special dynamic MLC delivery technique is considered similar to the static MLC delivery. In this delivery method, within each segment, the MLC leaf speed is zero, and the leaf speed is set to infinity between two segments, thus forcing the dose rate to be zero, i.e., the beam is off. It should be noted that this special dynamic MLC delivery is different from static MLC delivery, because in this special dynamic MLC delivery, the radiation and the leaf motion are still correlated. Despite their difference, both static MLC-IMRT delivery and special dynamic MLC-IMRT delivery are often referred to as step and shoot delivery. To distinguish these two delivery methods, we call the static MLC-IMRT delivery method mechanism I step and shoot delivery, in which each segment is considered as an individual field. The special dynamic MLC-IMRT delivery method is called mechanism II step and shoot delivery, in which the beam off/on command

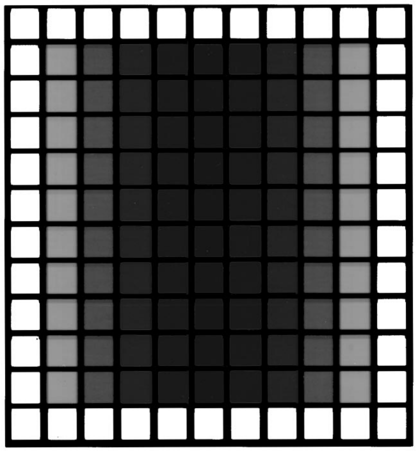


FIG. 1. A semi-Gaussian shaped intensity pattern, consisting of five intensity levels.

through a periodic comparison between the programmed MU to each segment and the cumulative MU controlled by the machine console.

The purpose of this paper is to investigate how the precision of the MU and the leaf position correlation varies as a function of the delivered MUs and dose rate in a commercial dynamic MLC system (Varian Oncology System, Palo Alto, CA).

II. MATERIALS AND METHODS

A. General description

The multileaf collimator in Varian's linear accelerator is a single-focused MLC,[12,13] in which a MLC field follows the beam divergence along the direction perpendicular to the leaf motion, but not along the direction of the leaf motion. In other words, the leaves move along straight lines in a plane perpendicular to the central axis of the beam. This design simplifies the mechanics of the MLC system, but may cause variations in the width of the penumbra when leaves move to different locations.[12,14] A rounded leaf end is used in this MLC system to minimize this effect.[15] Due to the rounded leaf end, however, the leakage between two leaves when they are closed is significant.[13] In conventional treatment, these closed leaf pairs are normally shielded under the primary and the secondary jaws to reduce the leakage between two leaf ends. In addition, to minimize leakage radiation between two adjacent leaves, a tongue and groove arrangement is used.

B. MLC control system

The MLC control system controls the movement of each MLC leaf, including verifying the correspondence of each leaf position with its programmed position stored in an ASCII file, referred to as a MLC file. The control system can be operated either in a static mode (for a conventional MLC field) or a dose mode (for an intensity modulated MLC field). In the static mode, there is only one position for each leaf for a given field. Once all leaves have moved to their pro-

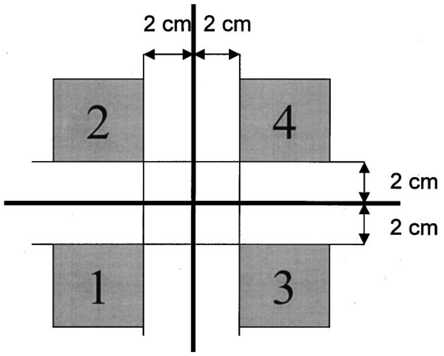


FIG. 2. A simple intensity pattern consisting of four 4×4 cm^2 square segments, located at an equal distance from the iso-center.

MU is delivered. In the dose mode, there are serial MLC positions for a given field stored in a MLC file, in which the positions of each MLC leaf are described as a function of a dose index ranging from 0.0 to 1.0. The dose index is a fraction of the total monitor units for the entire intensity modulated (IM) field.

C. Dynamic MLC delivery

In this system, the machine console and the MLC control station separately control the MU delivery and MLC positions, respectively. In conventional delivery, since only one MLC shape is associated with the total MU, the radiation beam is turned on only when the machine console receives a "ready" signal from the MLC control station. The communication between the MLC station and the machine console is sequential. Any delay in this communication would have no effect on the accuracy of the dose delivered to the field. In dynamic delivery, however, the leaf positions and the accumulated MUs are correlated. This correlation is established by communication between the MLC station and the machine console every 50 ms, independent of the complexity of the intensity profiles. In other words, the sampling frequency is fixed at 20 Hz.

Experiment A: Semi-Gaussian profile. Two experiments were designed to investigate the dose accuracy in IMRT delivery using the dynamic MLC. The first experiment was designed to study how a semi-Gaussian shaped intensity profile varies as a function of the dose rate and the delivered MU, using both the dynamic and mechanism II step and shoot delivery techniques. This semi-Gaussian shape produced a simple dose profile and semicontinuous dose intensity modulation across the field. Therefore, it is particularly suitable for dynamic delivery. The intensity map consists of five nonzero intensity levels, ranging from 20%, 40%, 60%, 80%, and 100% of the total MU, as shown in Fig. 1. This intensity map was manually input into the planning system (CORVUS 3.0, NOMOS Corp., Sewickley, PA), using the beam utility module. The MLC delivery files were created by the CORVUS system using the static and dynamic modes for Varian linear accelerators, respectively. At dose rates of 100 and 400 MU/min, total MUs of 1, 4, 16, 64, 100 MUs were delivered to the IM field. Films were used to measure the

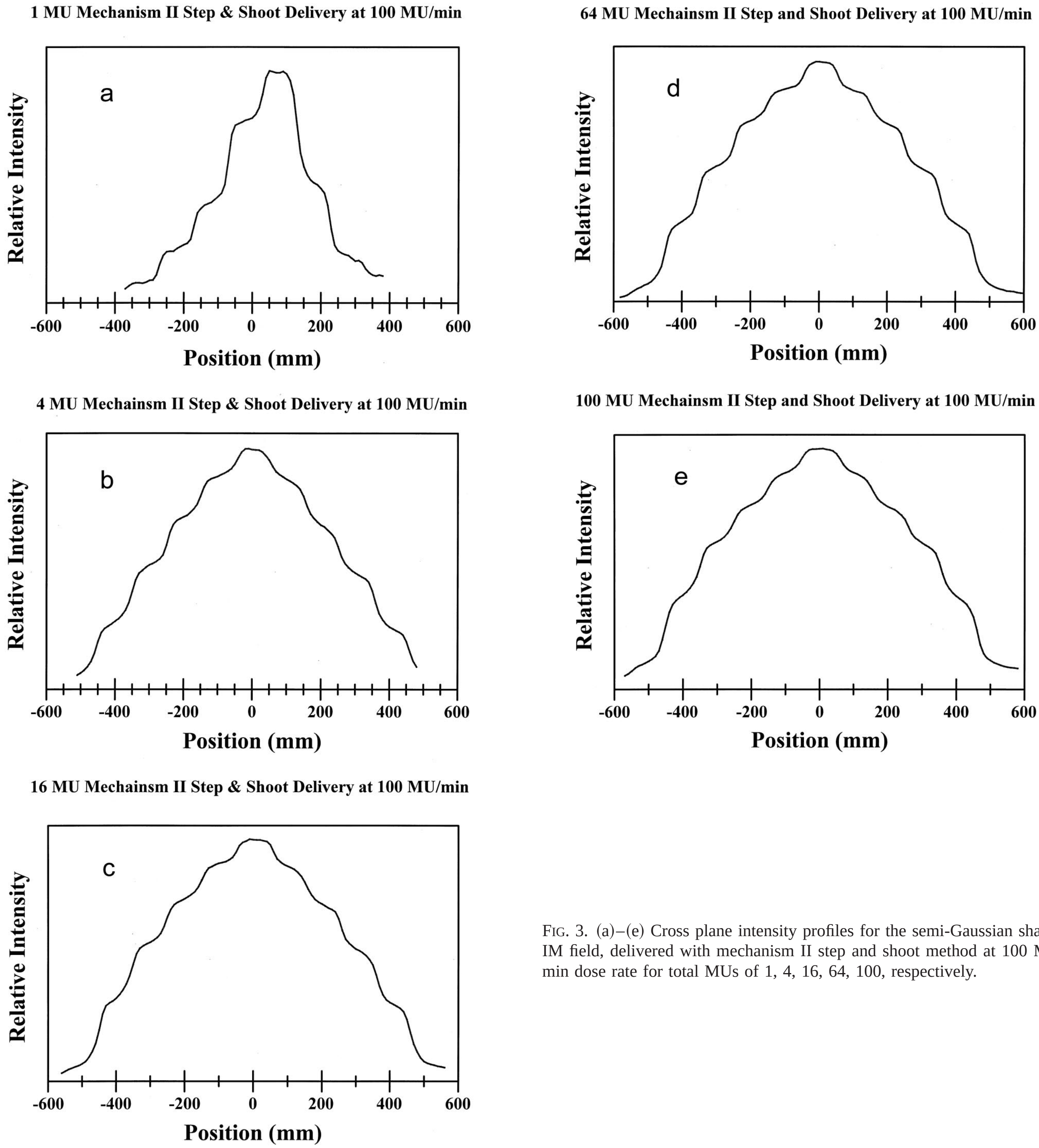
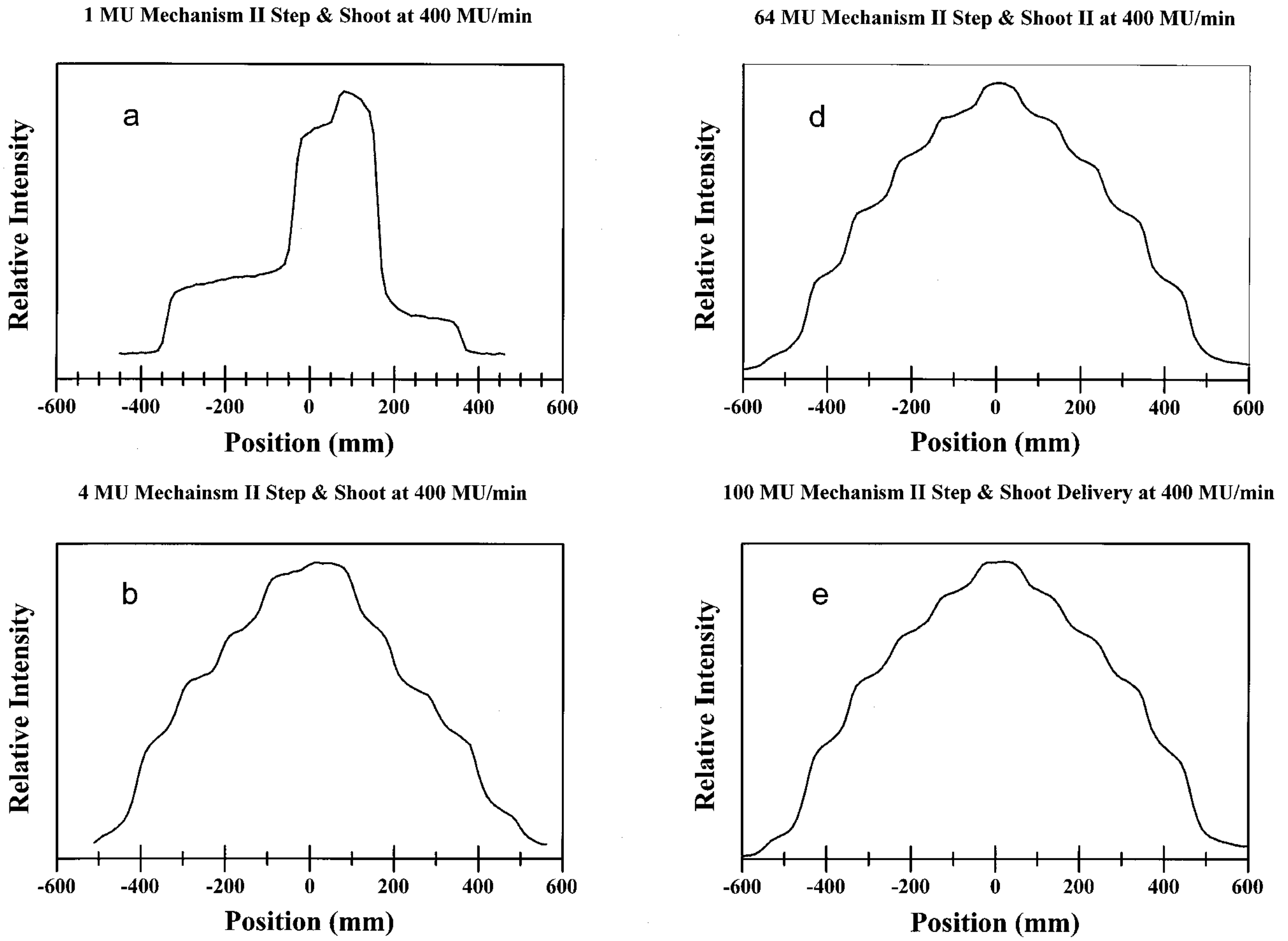


FIG. 3. (a)–(e) Cross plane intensity profiles for the semi-Gaussian shaped IM field, delivered with mechanism II step and shoot method at 100 MU/min dose rate for total MUs of 1, 4, 16, 64, 100, respectively.

sity, the enhanced contrast localization films (EC-L, Kodak, Rochester, NY) were used in a cassette for the measurement of 1 MU delivery. XTL films were used for the measurement of 4 and 16 MU delivery, and XV films were used for the measurement of 64 and 100 MU delivery. All films were exposed at 1.5 cm depth, 100 cm SSD, except the top surface of the EC-L film cassette was set at this depth, and irradiated at 6 MV. All films were scanned with a film scanner (VXR-12, Vidar Systems Corp., VA, using the Wellhofer

Experiment B: Four square intensity pattern. The second experiment was designed to deliver an intensity modulated field consisting of four $4\times4\ \mathrm{cm}^2$ segments located at an equal distance (5.66 cm) from the isocenter, as shown in Fig. 2. These four segments were first delivered with the mechanism I step and shoot method, in which the conventional delivery mode (or static mode in the VARIS system, Varian Oncology System, Palo Alto, CA) was used, with the same MU to each segment. This pattern was also delivered with



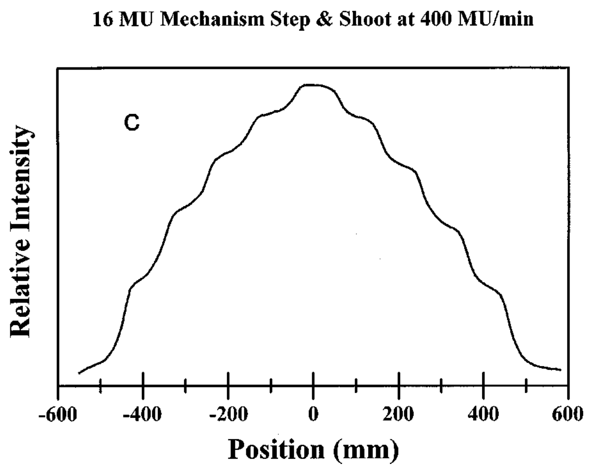


FIG. 4. (a)–(e) Cross plane intensity profiles for the semi-Gaussian shaped IM field, delivered with mechanism II step and shoot method at 400 MU/min dose rate for total MUs of 1, 4, 16, 64, 100, respectively.

mode in the VARIS system), with the same dose index to each segment. The MLC file for the mechanism II step and shoot delivery was created manually, following instructions in the DMLC manual (DMLC implementation Guide, Varian Oncology System, Palo Alto, CA). The MLC file consisted of a total of eight fields to describe the four segments, since each segment requires two MLC fields for the mechanism II step and shoot delivery. A Varian Clinac 2300 C/D, 6 MV photon beam energy was used. An ionization chamber (IC10, Wellhofer, Wellhofer North American, Bartlett TN) was used

water phantom with 100 cm source to surface distance. Because of geometric symmetry, the dose delivered to each segment should be the same, regardless of the delivery method. The relative dose difference Δ_i for each segment is defined as

$$\Delta_i = (D_i - D_0)/D_0, \quad (1)$$

where D_i is the dose measured in the ith segment and D_0 is the average dose of the four segments. This pattern was delivered at three different dose rates of 100, 400 and 600

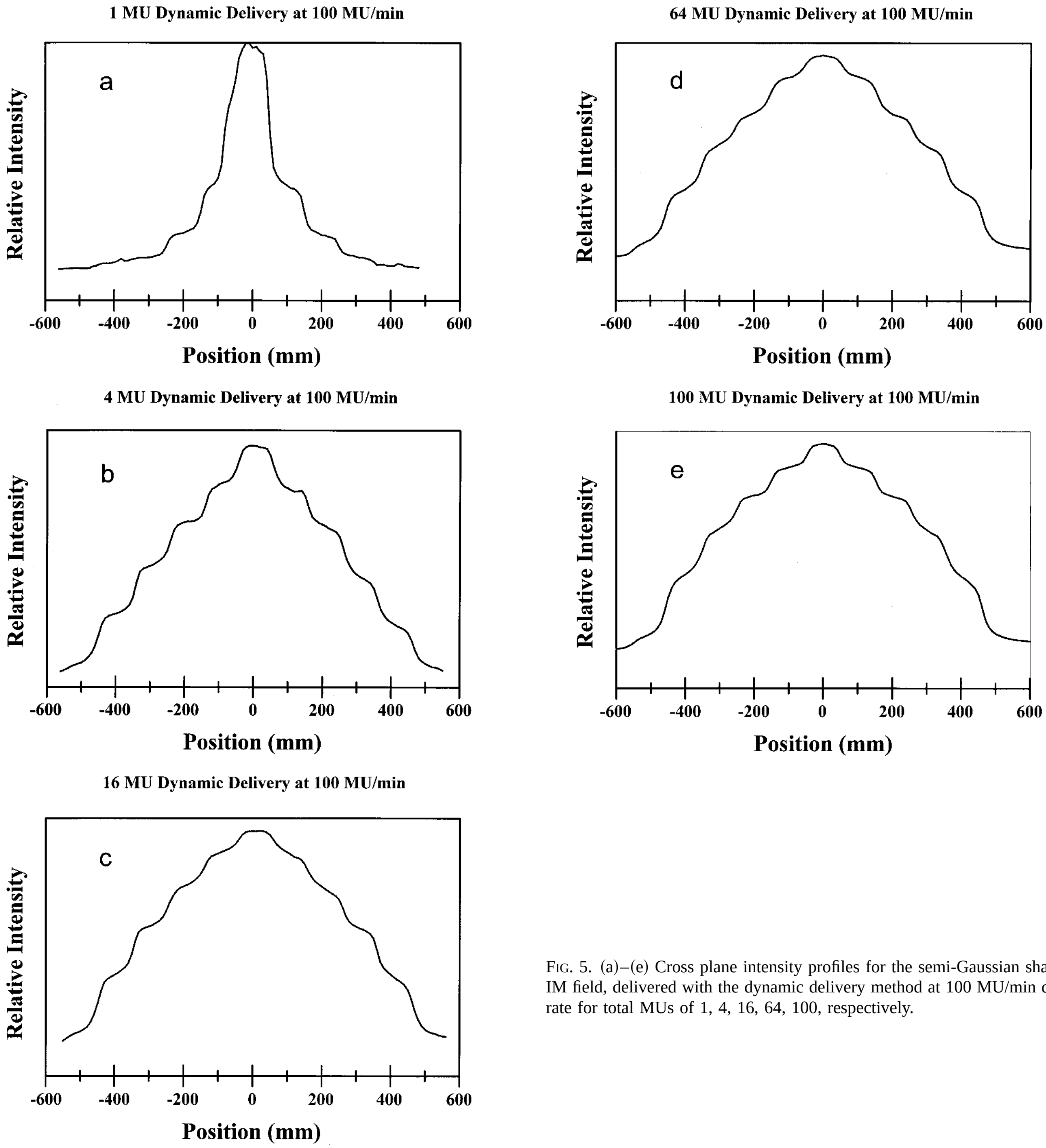


FIG. 5. (a)–(e) Cross plane intensity profiles for the semi-Gaussian shaped IM field, delivered with the dynamic delivery method at 100 MU/min dose rate for total MUs of 1, 4, 16, 64, 100, respectively.

tively. Since there were four segments in this IM field and each segment was assigned with the same MU, the MU per segment in these measurements was 0.25, 1, 4, 16, and 25 MU/seg, respectively.

III. RESULTS

Figures 3(a)–3(e) show cross plane profiles for the semi-Gaussian shaped IM field shown in Fig. 1, delivered with the mechanism II step and shoot method at 100 MU/min dose rate for total MUs of 1, 4, 16, 64, and 100, respectively. All

mum intensities. Since these profiles were obtained from three different kinds of films with different sensitivities, only the shapes of these profiles are important. The scales of the relative intensities, therefore, are not shown in Figs. 3(a)–3(e). Figures 4(a)–4(e) are cross plane profiles for the same IM field as in Fig. 3, but delivered at 400 MU/min dose rate. In Figs. 3 and 4, severe distortions were observed in profiles delivered with small MUs, such as in Figs. 3(a) and 3(b), and 4(a) and 4(b). The shorter the beam-on time, the more serious the observed distortions were. In Fig. 3(a), there is a

DOCKET ALARM

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts

Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research

With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips

Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.

WHAT WILL YOU BUILD? | sales@docketalarm.com | 1-866-77-FASTCASE

fastcase®
Smarter legal research.