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DATA DESCRIPTOR

Prostate intra-fraction motion recorded by transperineal ultrasound

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Infra-fraction motion of the prostate was recorded during 3.423 fractions of image guided radiotherapy (IGRT) in 191 patients, 14 of which were treated by intensity modulated radiation therapy (IMRT), and 177 of which were treated by volumetric arc therapy (VMAT). The prostate was imaged by three-dimensional and time-resolved transperineal ultrasound (4D-US) of type Clarity by Elekta AB, Stockholm, Sweden. The prostate volume was registered and the prostate position (center of volume) was recorded at a frequency of 2.0 samples per second. This raw data set contains a total of 1.985.392 prostate and patient couch positions over a time span of 272 hours, 52 minutes and 34 seconds of life radiotherapy as exported by the instrument software. This data set has been used for the validation of models of prostate intra-fraction motion and for the estimation of the dosimetric impact of actual intra-fraction motion on treatment quality and side effects. We hope that this data set may be reused by other groups for similar purposes.

Background & Summary

Image guided radiotherapy (IGRT) employs various imaging modalities such as computed tomography (CT), cone beam CT (CBCT), stereoscopic x-ray imaging, or ultrasound to locate the target volume and surrounding organs at risk. In particular, the location of the tumour can be used to correct for positioning errors between fractions (inter-fraction) or even in real-time during treatment (intra-fraction).

In our study, we used time-resolved 3D ultrasound (4D-US) to monitor intra-fraction motion of the prostate during primary radiotherapy of adenocarcinoma. We used a trans-perineal robotic probe (Clarity system by Elekta AB, Stockholm, Sweden) which remained fixed to the patient couch and automatically scanned and recorded the prostate position during treatment fractions.

The data we acquired was used to validate the random walk model of intra-fraction motion[1], investigate a potential impact of patient couch shifts on intra-fraction motion[2], to estimate the impact of ultrasound probe pressure on intra-fraction drift of the prostate[3], to show that a shorter treatment time reduces the severity of intra-fraction motion[4] and to estimate the dosimetric impact of intra-fraction motion on boosts on intra-prostatic lesions[5].

The dataset described here is a direct extension of the data of the first 28 resp. 126 patients made available in 2019[6] and 2022[7]. The data has been reused by us to identify personalized confounding factors for patients at risk of high prostate motality[8] and by other groups to develop methods for fast adaptive replanning during robotic SBRT[9] or for dosimetry validation in heterogeneous phantoms[10].

Our investigation is in line with other research that employs the Clarity system to record intrafraction motion of the prostate. Such data has been used, for example, for safety margin validation (N = 14)[11], to measure intrafractional prostate motion and potential correlation with body mass index (N = 10)[12], to evaluate intrafraction monitoring (N = 20)[13] resp. (N = 17)[14] resp. (N = 16)[15], to reduce toxicity in hypofractionated/stereotactic prostate radiotherapy (N = 25)[16], or to compare ultrasound imaging to EM transmitter tracking (N = 10)[17].

In general, intrafraction motion data of the prostate may help to improve personalized safety margins and to generally improve tumor control probability and to reduce side effects to organs at risk. We find it a valuable tool in treatment quality control and hope that a free and open data set of N = 191 patients will be useful in this context.

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Methods

The study is based on 191 patients with adenocarcinoma of the prostate who received a definitive external beam radiotherapy between June 2014 and August 2023 at our department guided by 4D ultrasound (Clarity IGRT workflow). The first 14 patients of these were treated with IMRT (before May 2015). The latter 177 patients, starting afterwards, received VMAT. The set up remained otherwise unchanged.

The decision to switch the treatment regime from IMRT to VMAT in 2015 was made purely for clinical reasons and blind to the results of this study. While this is a retrospective study, the decision was made to evaluate as soon as an equal number of patients had been recorded with VMAT as with IMRT.

Patients were positioned pre-fraction on a 3-DOF robotic couch, matching daily kV-CBCTs to the planning CT. Shifts in vertical, longitudinal, and lateral direction were then corrected by automatic repositioning of the couch. Rotational shifts were not corrected. The new position of the prostate was then used as the reference position. This procedure was repeated before each fraction.

Intra-fraction motion of the prostate was then monitored and recorded by robotic trans-perineal 4DUS using the Clarity system by Elekta AB, Stockholm, Sweden with an auto-scan probe[12,18]. Patients were placed in supine treatment position, knees on elevated cushions, legs moderately spread. There were no catheters, rectal balloons, spacers or other devices in use to affect intra-fraction motion. The ultrasound probe was fixed to the treatment table and made gel-mediated contact with the perineum at intermediate pressure[3].

A total of 3.423 fractions was recorded. This corresponds to a mean of 17.9 and a median of 18 recorded fractions per patient, compared to typically 20 to 30 fractions delivered per patient. The decision to record a particular fraction with 4DUS (in addition to mandatory daily initial patient setup control by both kV-CBCT and 3DUS) was made by technical personnel based on daily clinical workload. There is no indication that the recorded fractions were not representative of an average fraction.

A total of 272 hours, 52 minutes and 34 seconds of intra-fraction motion was recorded during which 1.985.392 position measurements were acquired at a rate of 2.0 per second. The data was exported from the instrument software, Clarity AFC Workstation version 4.4.0.528.

Human subjects. The study did not involve any experiments on human subjects. All data was generated retrospectively from quality control data acquired in a non-invasive and dose-free fashion during standard treatment independent of this study. The study was conducted in accordance with the Declaration of Helsinki and was approved by the Institutional Review Board (or Ethics Committee) of the Medical Faculty of LMU Munich (protocol codes 19–351 and 19–361, both of August 1st, 2019). Informed consent was obtained from all subjects involved in the prospective study starting 08/2019. Patient consent was waived due to the provisions of Article 16 Section (3) Number 2 of the law governing the university hospitals in the state of Bavaria for the retrospective analysis of data older than 08/2019.

Data Records

The complete raw data is stored in a public open access repository[19] at https://doi.org/10.5282/ubm/data.428.

The data is stored in two archive files in .zip and .tar format, respectively, with identical content. The content is organized in 3.423 separate files in comma separated values (CSV) format. The files are named 'patient_[ppp]_fraction_[nnn].csv' where [ppp] counts the patients, starting with '001', and [nnn] counts the fractions of each patient, starting over with '001' for each patient.

Table 1 gives an overview of the available data. For example, the data corresponding to the 24 fractions recorded for the first patient is contained in 'patient_001_fraction_001.csv' through 'patient_001_fraction_024.csv'.

Each CSV files holds a large number of rows, each corresponding to one recorded data point in time, at a sample frequency of about 2.0 Hz.

Table 2 gives an overview of the columns the data is organized into:

Iso8601Time is a time stamp in ISO 8601 format (YYYY-MM-DDThh:mm:ss.sss). Its absolute value is not meaningful, as the workstation's internal clock may or may not have been correctly set at all times (in particular, due to regional daylight-saving settings). However, the time stamps are essential in calculating relative durations. It is useful to define the begin of a treatment fraction as arbitrary zero.

SecondsFromMidnight is a time stamp in seconds (and milliseconds in the decimal places). As before, it is useful to define durations and one should choose an arbitrary zero.

XShift denotes the recorded position of the prostate on the **longitudinal** axis in units of mm. As the patient is lying on the treatment couch, this axis is horizontal in the laboratory frame of reference and points away from the gantry. Positive and increasing values describe a motion in caudal direction, away from the gantry **(inferior, INF, +)**. Negative and decreasing values describe a motion in cranial direction, towards the gantry **(superior, SUP, −)**. The absolute value of this quantity is not meaningful, one should define a suitable zero.

YShift denotes the recorded position of the prostate on the **lateral** axis in units of mm. As the patient is lying on the treatment couch, this axis is horizontal in the laboratory frame of reference and parallel to the gantry. Positive and increasing values describe a motion towards the left side of the patient **(left, LT, +)**. Negative and decreasing values describe a motion towards the right side of the patient **(right, RT, −)**. The absolute value of this quantity is not meaningful, one should define a suitable zero.

ZShift denotes the recorded position of the prostate on the **vertical** axis in units of mm. As the patient is lying on the treatment couch, this axis is also vertical in the laboratory frame of reference and points up. Positive and increasing values describe a motion in anterior direction, or upwards **(anterior, ANT, +)**. Negative and decreasing values describe a motion in posterior direction, or downwards **(posterior, POST, −)**. The absolute value of this quantity is not meaningful; one should define a suitable zero.

Patient	Treatment	Day of first fraction	Number of recorded and delivered fractions	Data files - [nn] runs from 01 to the number of recorded fractions
patient_01	IMRT	2014-06-16	24 of 37	patient_001_fraction_[nnn].csv
patient_02	IMRT	2014-07-14	15 of 36	patient_002_fraction_[nnn].csv
patient_03	IMRT	2014-09-29	27 of 37	patient_003_fraction_[nnn].csv
patient_04	IMRT	2014-09-30	29 of 37	patient_004_fraction_[nnn].csv
patient_05	IMRT	2014-09-30	32 of 38	patient_005_fraction_[nnn].csv
patient_06	IMRT	2014-11-25	31 of 37	patient_006_fraction_[nnn].csv
patient_07	IMRT	2015-01-05	19 of 38	patient_007_fraction_[nnn].csv
patient_08	IMRT	2015-01-12	23 of 36	patient_008_fraction_[nnn].csv
patient_09	IMRT	2015-02-02	16 of 38	patient_009_fraction_[nnn].csv
patient_10	IMRT	2015-03-09	22 of 37	patient_010_fraction_[nnn].csv
patient_11	IMRT	2015-04-20	29 of 38	patient_011_fraction_[nnn].csv
patient_12	IMRT	2015-05-05	35 of 38	patient_012_fraction_[nnn].csv
patient_13	IMRT	2015-05-18	34 of 35	patient_013_fraction_[nnn].csv
patient_14	IMRT	2015-05-21	34 of 37	patient_014_fraction_[nnn].csv
patient_15	VMAT	2015-09-29	31 of 36	patient_015_fraction_[nnn].csv
patient_16	VMAT	2016-05-02	28 of 37	patient_016_fraction_[nnn].csv
patient_17	VMAT	2016-05-12	29 of 37	patient_017_fraction_[nnn].csv
patient_18	VMAT	2016-06-02	26 of 36	patient_018_fraction_[nnn].csv
patient_19	VMAT	2016-06-23	35 of 37	patient_019_fraction_[nnn].csv
patient_20	VMAT	2016-07-04	27 of 38	patient_020_fraction_[nnn].csv
patient_21	VMAT	2016-10-10	34 of 37	patient_021_fraction_[nnn].csv
patient_22	VMAT	2016-12-20	31 of 36	patient_022_fraction_[nnn].csv
patient_23	VMAT	2017-01-02	33 of 38	patient_023_fraction_[nnn].csv
patient_24	VMAT	2017-01-19	30 of 38	patient_024_fraction_[nnn].csv
patient_25	VMAT	2017-01-26	31 of 38	patient_025_fraction_[nnn].csv
patient_26	VMAT	2017-01-31	27 of 38	patient_026_fraction_[nnn].csv
patient_27	VMAT	2017-03-21	16 of 38	patient_027_fraction_[nnn].csv
patient_28	VMAT	2017-03-23	17 of 38	patient_028_fraction_[nnn].csv
…	…	…	…	patient_[mmm]_fraction_[nnn].csv

Table 1. Summary of input data and corresponding data file names.

Field name	Unit	Explanation and remarks
Iso8601Time	s	time stamp in ISO 8601 format (YYYY-MM-DDThh:mm:ss.sss)
SecondsFromMidnight	s	seconds since midnight (ss.sss)
XShift	mm	prostate position (longitudinal axis, + = inferior "INF", - = superior "SUP")
YShift	mm	prostate position (lateral axis, + = left "LT", - = right "RT")
ZShift	mm	prostate position (vertical axis, + = anterior "ANT", - = posterior "POST")
CouchRelativeX	mm	couch position (longitudinal axis, + = inferior "INF", - = superior "SUP")
CouchRelativeY	mm	couch position (lateral axis, + = left "LT", - = right "RT")
CouchRelativeZ	mm	couch position (vertical axis, + = anterior "ANT", - = posterior "POST")

Table 2. Data format explained.

CouchRelativeX, CouchRelativeY, CouchRelativeZ describe the **absolute** position of the patient couch with respect to the laboratory frame of reference (i.e. relative to the floor of the treatment room or relative to the beam center), again on the longitudinal, lateral, and vertical axis and with the same orientations as before.

XShift, YShift, and **ZShift** describe the change in position (shift) of the prostate **relative** to the ultrasound probe, which is fixed to the patient couch. Unless the patient moves on the patient couch, this shift also describes the relative motion of the prostate in the patient.

Thus, if one is interested in the physiological motion of the prostate, one should simply consider XShift, YShift, and ZShift, see Fig. 1. However, if one is interested in the absolute motion of the prostate, e.g. relative to the treatment beam, one should consider **XShift + CouchRelativeX, Yshift + CouchRelativeY**, and **ZShift + CouchRelativeZ**, respectively, see Fig. 2.

The naming and definition of these columns have remained unchanged since the first version of this dataset. However, two earlier columns "Quality" and "HasCouchRelativePosition" were omitted from this version. Otherwise, users may combine and compare earlier versions without translation.

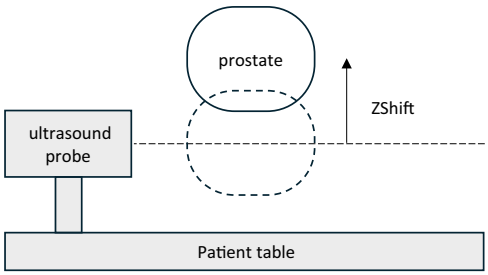

Fig. 1 Coordinate system relative to ultrasound probe registers movements by the patient/prostate relative to the patient table.

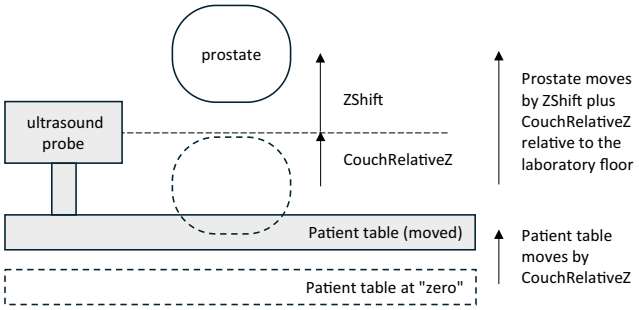

Fig. 2 Coordinate system relative to the laboratory floor registers movements by the patient/prostate plus movements by the patient table.

Technical Validation

The spatial resolution of the ultrasound system is specified by the manufacturer to about 0.2 mm[18]. The overall geometric inaccuracy of a very similar setup due to inherent technical limitations was measured to be 0.6 mm laterally, 0.7 mm vertically, 0.5 mm longitudinally, and 1.1 mm radially ('vector length' or Euclidean '3D-distance'; the square root of the sum of squares of the three axes) consisting of random errors (per single measurement point) and systematic errors (effectively, per fraction)[20]. The temporal resolution of the device is specified to about 2 Hz[18]; data was in fact recorded at 1.6 Hz on average.

The particular setup used in this study has been characterised before in detail[21]. The discrepancy between ultrasound localisation and implanted gold markers detected by CBCT was 0.0 ± 1.7 mm laterally, 0.2 ± 2.0 mm longitudinally, and 0.3 ± 1.7 mm vertically. Using implanted gold markers as a reference, systematic errors for ultrasound localisation were 1.2 mm, 1.1 mm, and 0.9 mm; and random errors were 1.4 mm, 1.8 mm, and 1.6 mm, on lateral, longitudinal, and vertical axes, respectively. The majority of these errors stems from inter-modality comparisons; within the modality accuracy and repeatability were generally sub-millimeter. The setup was routinely gauged during weekly QA.

The motion management system of the Clarity system was used to shut off the beam whenever the prostate position exceeded a certain threshold per axis. In such cases, the table position was manually corrected and the prostate position checked before treatment was resumed. However, this motion of the table did not produce any excessive acceleration that could have caused prostate motion of its own. In particular, we checked[2] that the table motion was not visible in the prostate motion data as the prostate position was recorded relative to the table and not in absolute room coordinates. Therefore, our simulation resembles a situation before or without active prostate motion management and correction.

Usage Notes

In our own analysis, we first visually inspected the prostate trajectories one by one. The data features begin-of-fraction and end-of-fraction outliers, e.g. caused by patients leaving their position after treatment is stopped. We opted, however, to leave the full original raw data in the deposited dataset, including outliers.

It is useful to resample the data to reduce high frequency noise and to equalize the time intervals (readouts do not occur perfectly equitemporal). In our own analysis, we typically chose bins of five-second intervals.

The data is publicly available from Open Data LMU under CC BY 4.0 license. There are no access controls in place. Use of the data is not limited.

Code availability

All data is provided as human readable ASCII text in CSV format and can be browsed and processed without proprietary code.

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Author contributions

Hendrik Ballhausen exported the data, processed the dataset and wrote the data descriptor. Minglun Li designed the study and was responsible for the collection of the data. Claus Belka designed the study and provided clinical oversight and guidance. All authors read and approved the final version of the data descriptor.

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Competing interests

The authors declare no competing interests.

Additional information

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