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Original Article

Radium-223 IN metastatic hormone-sensitive high-grade prostate cancer: initial experience

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Abstract: Our study evaluates the feasibility of compassionate exemption of Radium-223 (^{223}Ra) treatment in metastatic hormone-sensitive high-grade prostate cancer (mHSHGPC) patients with concomitant androgen deprivation-therapy (ADT). Seven patients with mHSHGPC, were treated with six cycles of ^{223}Ra plus ADT. All patients had undergone to ^{18}F-NaF-PET/CT. A qualitative analyses of the ^{18}F-NaF-PET/CT was performed in conjunction with Alkaline Phosphatase (ALP), Lactate-dehydrogenase (LDH) and Prostatic-Specific Antigen (PSA) values. The mean of SUVmax values were used as a quantitative measure of tumoral burden. Changes in PSA, ALP, LDH from baseline were evaluated, and were defined as increase or decrease of at least 30%. Clinical response was achieved if there was pain reduction using visual analogic scale. Four patients showed a significant reduction in mean SUVmax after 3 cycles of ^{223}Ra, and one after 6 cycles. Patients who showed reductions in mean SUVmax after Ra-223 also showed reductions in PSA, ALP and LDH. Four weeks after the last cycle of ^{223}Ra all patients had decreased total PSA, ALP and LDH values ≥ 30% also significant improvement on pain. No progress disease was documented after 14 ± 4 weeks. We found slight to moderate decreases in neutrophils and hemoglobin in two patients. We concluded that ^{223}Ra plus ADT can be useful in mHSHGPC; the semi-quantitative ^{18}F-NaF-PET/CT as a method effective to monitor the treatment response. Due to concomitant administration of ADT, ^{18}F-NaF-PET/CT cannot differentiate whether the findings were due to androgen blockade or the ^{223}Ra; nevertheless, data supporting the efficacy of ^{223}Ra is the significant improvement on pain.

Keywords: Ra-223, ^{18}F-NaF PET/CT, prostate cancer high-grade, hormone-sensitive

Introduction

Prostate cancer (PC) is the most common cancer in men and represents the third most common cause for death in men cancer-associated [1]. Early detection of primary disease is highly relevant in terms of prognosis and therapy management.

In Mexico PC represents the first malignant neoplasm in men with highest incidence and mortality. More than 50% of the patients who underwent an initial evaluation have metastatic disease [2, 3]. These patients usually respond to androgen deprivation therapy (ADT); however, most patients do not respond to pain, despite optimal painkillers [4]. In 2015, 2 large randomized trials demonstrated the survival benefit of docetaxel in hormone sensitive prostate cancer, showing for the first time that treatment with drugs with benefit in the context of the castrate resistant disease, could be more beneficial if they were used earlier in the course of the disease [5, 6]

Radium-223 (^{223}Ra) is a bone-seeking radiopharmaceutical that emits α-particles that deposit high linear energy within a short penetration range to areas of increased bone turnover, as radioactive decay occurs, near osseous metastatic sites, it selectively kills cancer cells. ^{223}Ra has a complex decay scheme in which 4 alfa particles resulting in high energy deposition (28.2 MeV), the high linear energy transfer of radiation results in generation of double-strand DNA breaks, and gives rise to cytotoxicity that is independent of dose rate, cell cycle growth phase, and oxygen concentra-

tion. The range of the α particles (< 100 μm) results in less hematologic toxicity than expected from β emitters [7, 8].

^{223}Ra was the first bone-targeting agent to demonstrate improved overall survival in patients with Castration Resistant Prostate Cancer (CRPC) and bone metastases, in addition to bone pain relief, improvement in quality of life (QoL), and prolonging time to skeletal-related events (SREs) [9, 10].

In the present study, we evaluate the feasibility of compassionate exemption ^{223}Ra treatment, with concomitant ADT, in metastatic hormone-sensitive high-grade prostate cancer (mHSHGPC) patients with multiple painful bone metastases.

Materials and methods

Patients

Patients with histologically confirmed, mHSHGPC, evidence of more than 10 metastatic bone sites, evaluated by bone scintigraphy at diagnosis, and bone pain as predominant symptom, were included. All the patients required hematological parameters within normal reference values (neutrophils ≥ 1.5 × 10^9/L, platelets ≥ 100 × 10^9/L, hemoglobin ≥ 10 g/dL) before the application of ^{223}Ra which were obtained 1 ± 5 days before the application. Patients with evidence of visceral metastases, lymph nodes metastases > 3 cm in long-axis diameter, confirmed by a CT scan, or ADT initiation more than 3 months, were excluded. Other exclusion criteria included history of cancer other than prostate cancer, recent or complicated nonhealing fracture, and use of concomitant radiotherapy. Treatment with ADT was initiated after diagnosis of mHSHGPC and before compassionate exemption of ^{223}Ra treatment, and was given continuously. ADT included bicalutamide 150 mg per day + luteinizing hormone-releasing hormone agonist (leuprolide) 11.25 mg every three months.

Imaging protocol

Patients underwent to 370 MBq (10 mCi) sodium fluoride PET/CT (^{18}F-NaF-PET/CT) whole body scan 1 ± 5 days prior to the administration of ^{223}Ra, as per institution protocol. Each hybrid PET/CT (mCT LSO; Siemens, Erlangen, Germany) was performed 1 hour after IV administration of the radiotracer. Low-dose helical CT transmission scan [pitch 0.8, 50 mA s, 120 kV (peak)] was performed. PET acquisition was started at a mean time of 59 ± 10.1 min after tracer injection (range, 49-70 min). PET was then performed within 2 minutes per bed position at a sufficient number of bed positions to cover the anatomic regions from the top of the head to the feet. Raw CT data were reconstructed into 5-mm thick section of transverse images, and reformatted sagittal and coronal CT images were generated. CT-based attenuation-corrected PET images were reconstructed and viewed on a high-resolution colored monitor. PET and CT images could be viewed on a continuous fusion scale from PET only to CT only images using image fusion software (E-soft; Siemens). In addition to quantifying the osteoblastic lesions, the median values of SUV were obtained to assess tumor burden.

Image interpretation

Fused PET/CT images for each scan were interpreted by 2 board-certified nuclear medicine physicians with more than 4 years of experience interpreting hybrid PET/CT studies. No reader for a particular scan was aware of the findings on the other paired scan. All interpreted pairs of PET/CT studies were again reexamined for agreement by consensus. Maximum-intensity-projection images were examined to help facilitate lesion detection. All maximum standardized uptake value (SUVmax) values of suspicious lesions (defined as foci of nonphysiological uptake above regional background activity associated with osteoblastic lesions by tomography findings) were obtained using 3D region of interest with the vendor-provided software (syngo by SIEMENS). After measurement of all metastatic lesions, mean values were obtained. A region of interest (ROI) was outlined within areas of increased uptake and measured on each slice. When the lesion was extensively heterogeneous, the ROI was set to cover all the components of the lesion. The SUVmax was recorded by using the maximum pixel activity within the ROI and measurement of all the metastatic lesions, finally obtaining a mean value for each patient.

^{223}Ra treatment

Patients were administered intravenous ^{223}Ra at 50 kBq/kg body weight (until May 2016,

Table 1. Baseline characteristics of patients studied

Patient	Age	Gleason score	PSA (ng/ml)	AP (UI/l)	LDH (UI/l)	VAS	Therapy initiated
1	64	9	234	554	285	9	LHRH + Bicalutamide
2	59	8	530	200	198	10	LHRH + Bicalutamide
3	46	9	220	443	245	8	LHRH + Bicalutamide
4	64	9	36.4	160	291	8	LHRH + Bicalutamide
5	70	9	421	788	450	9	LHRH + Bicalutamide
6	66	8	199	245	209	8	LHRH + Bicalutamide
7	71	9	604	647	551	10	LHRH + Bicalutamide

PSA: Prostatic specific antigen; AP: Alkaline Phosphatase; LDH: Lactate Dehydrogenase; VAS: Visual Analog Scale for Pain; LHRH: luteinizing hormone-releasing hormone.

Table 2. Baseline characteristics before starting treatment with Ra-223

Patient	Metastatic sites	Mean SUVmax (Range)	PSA (ng/ml)	ALP (UI/L)	LDH (UI/L)	VAS	Hb (g/dl)	Plt ($\times 10^3$/μL)	Neutrophils ($\times 10^3$/μL)	Leukocytes ($\times 10^3$/μL)	Previous RT
1	SUPERSCAN	91.6 (79.1-144.1)	3.2	270	181	8	13.3	286	4.5	7.2	NO
2	15	66.8 (26.9-84.2)	34	196	189	8	12.9	190	4.1	5.5	SI
3	12	58.7 (22.5-76.4)	26	348	207	8	14.8	323	5.4	5.1	NO
4	> 20	81.7 (33.1-91.9)	36.4	160	291	8	14.2	263	3.8	7.3	NO
5	18	69.1 (36.9-101.2)	18.3	455	299	7	11.1	328	3.2	4.2	NO
6	> 20	89.7 (53.1-101.6)	6.7	211	189	7	13.1	401	3.7	4.5	NO
7	SUPERSCAN	96.6 (84.7-155.0)	71	901	604	7	12.1	388	2.9	3.1	SI

RT: Radiotherapy; Hb: Hemoglobin; Plt: platelets.

after this point the dose were calculated at 55 kBq/kg body weight after implementation of National Institute of Standards and Technology update on April 18, 2016) every 4 weeks for 6 cycles. Previous to each cycle, absolute blood count (hemoglobin, erythrocytes, leukocytes, platelets, neutrophils and lymphocytes) was evaluated. Treatment was continued as long as absolute blood count was ≥ 1.0 g/L for neutrophils and ≥ 50 g/L for platelets. Written informed consent was obtained from each patient before administration of ^{223}Ra (**Table 1**).

Other response assessments

Alkaline phosphatase (ALP), Lactate dehydrogenase (LDH), Prostatic specific-antigen (PSA) and ^{18}F-NaF-PET/CT were acquired prior cycle 1, 4, and 4 weeks after cycle 6. The follow-up visit was 14 ± 4 weeks after the last administration of ^{223}Ra. Changes in ALP, LDH and PSA were recorded. Clinical response was achieved if there was pain reduction using visual analogic scale. Molecular response was assessed by ^{18}F-NaF-PET/CT whole body scan, and was defined as any measurable decrease in the sum of the osteoblastic metastatic disease of all pre-therapeutically detected tumor lesions.

Statistical analysis

A qualitative comparison of the ^{18}F-NaF-PET/CT whole body scans was performed in conjunction to the ALP, LDH and PSA results. A semi-quantitative comparison was performed by measuring the SUVmax values in all bone metastases in each patient. The means of the lesions SUVmax measurements in each patient were used as a quantitative measure of global metastatic activity previous to receive the first cycle of ^{223}Ra, after 3 and after 6 cycles of ^{223}Ra. Changes in PSA, ALP, LDH from baseline were evaluated, and were defined as an increase or a decrease of at least 30% from baseline.

Results

From January 2015 to December 2016, 7 patients with mHSPC were treated with ^{223}Ra + ADT. All patients had bone metastases without soft-tissue lesions or visceral metastases at diagnosis; they all had baseline bone scans. None of the patients were pretreated with ^{223}Ra or another bone seeking radiopharmaceutical. Two patients had a history of localized radiotherapy (3 months before starting treatment

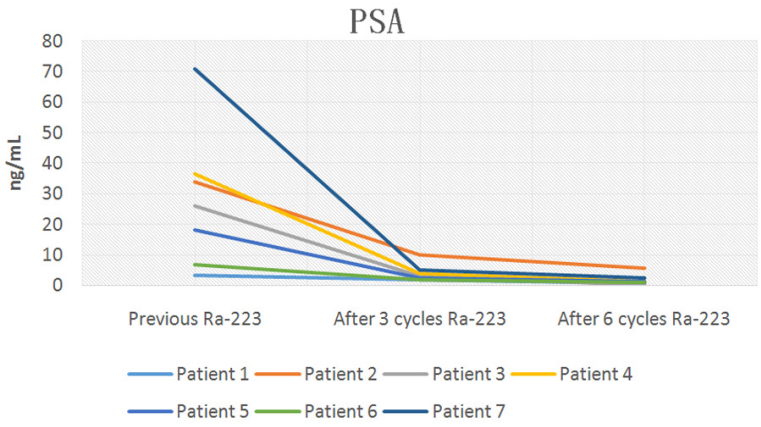

Figure 1. Baseline Prostate specific-antigen and subsequent levels after 3 and 6 doses of ^{223}Ra plus ADT.

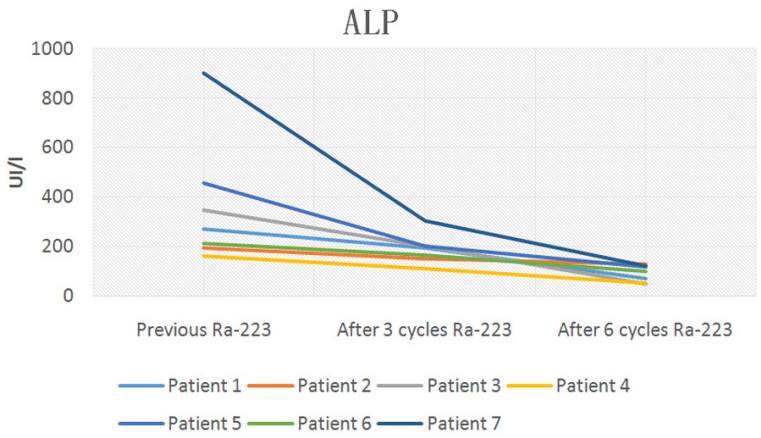

Figure 2. Baseline Alkaline Phosphatase and subsequent levels after 3 and 6 doses of ^{223}Ra plus ADT.

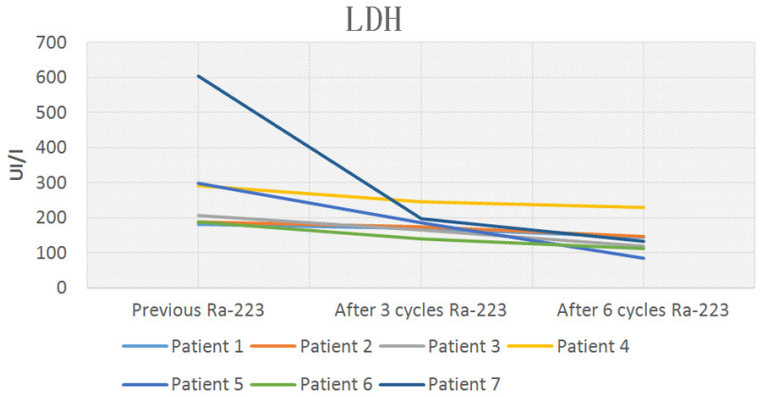

Figure 3. Baseline Lactate dehydrogenase and subsequent levels after 3 and 6 doses of ^{223}Ra plus ADT.

with ^{223}Ra) to bone, due to intense pain, at diagnosis. All patients had pain at least VAS 7, despite to receive painkillers such as NAIDS and opioids. Baseline characteristics before starting treatment with ^{223}Ra are presented in **Table 2**. All patients were evaluated with ^{18}F-NaF-PET/CT whole body scan 1 ± 1 week before starting treatment with ^{223}Ra. Osteoblastic lesions were selected to represent both axial and appendicular sites when present, and the SUVmax calculated from a ROI of each lesion. The average SUVmax of the total lesions was then calculated for each patient at each scanning time point.

Four patients had high tumor burden, two of them had a "superscan" with high mean SUVmax (81.7; 89.7; 91.2 and 96.6, respectively). Six patients had high values of ALP before to start treatment with ^{223}Ra (where the median value was 270 UI/l [range 196-901 UI/l]); five of these associated to high values of PSA (where the median value was 26 ng/ml [range 3.2-71 ng/ml]) and LDH (where the media value was 207 UI/l [range 181-604 UI/l]).

Therapy with ^{223}Ra was started 2.2 ± 1.1 months after initial diagnosis of metastatic prostate cancer. All patients completed all six cycles of ^{223}Ra (mean cumulative dose 28.6 ± 3.8 MBq).

In the semi-quantitative analysis, four patients showed a significant reduction in mean SUVmax after 3 cycles of ^{223}Ra, and one other showed a significant reduction after 6 cycles. One patient showed minimal changes after 3 and 6 cycles of ^{223}Ra. In six patients' partial response based in extent of disease and intensity (osteoblastic activity) were observed,

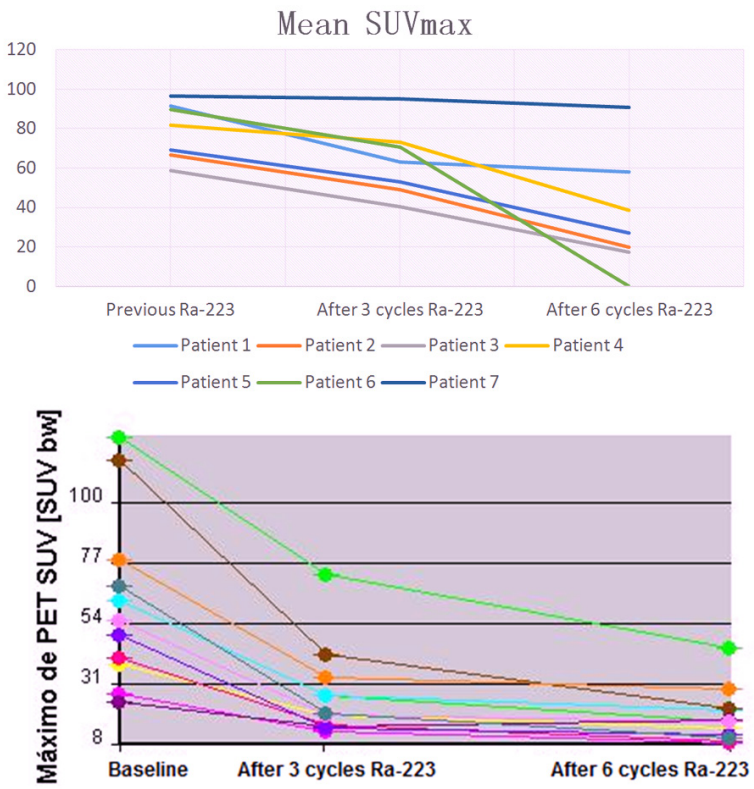

Figure 4. *Top.* Semi-quantitative analysis of Mean SUVmax metastatic lesions baseline and after 3 and 6 doses of ^{223}Ra plus ADT. *Lower.* The average SUVmax of the total lesions for each patient at each scanning time point.

although not directly measuring tumour cell activity, as might be possible with other PET radiotracers including ^{18}F-fluorodeoxyglucose, ^{68}Ga-prostate-specific membrane antigen, changes in ^{18}F-NaF uptake were similar to changes in ALP, PSA, LDH after 6 cycles of ^{223}Ra. In one patient stable disease was documented after six cycles of ^{223}Ra. No progression of disease was documented. All patients who showed reductions in mean SUVmax after ^{223}Ra treatment also showed reductions in PSA, ALP and LDH, including the patient with minimal changes visualized by PET/CT; the overall changes by each patient are shown in **Figures 1**-**4**. Of interest, an increase of sclerotic lesions was noted after treatment with ^{223}Ra (**Figures 5** and **6**).

Table 3, shows tumor markers evaluated and potential tumor-volume-related determinants in serum after 6 cycles of ^{223}Ra. Total PSA, ALP and LDH decreased significantly during ^{223}Ra therapy. Three months after treatment initiation with ^{223}Ra, five of the seven patients had decreased total PSA, ALP and LDH values. Four weeks after the last cycle of ^{223}Ra all patients had decreased total PSA, ALP and LDH values greater than or equal to 30% below the baseline.

Improvement of bone pain was observed in all patients at the end of treatment compared to baseline. In three patients a significant decrease in pain was observed after the first two cycles of ^{223}Ra; in two patients after four cycles.

Treatment-related adverse events were observed in two patients (patients with superscan); such as fatigue, diarrhea and nausea; meanwhile did not affect continuation of therapy. We found slight to moderate decreases in neutrophils and hemoglobin in two patients at the end of entire therapy. During treatment and at term, no patient required transfusion. One patient (with superscan) required prior to the last cycle administration of colony stimulating factor. None patient presented severe adverse event's Grade III or IV according to Common Terminology Criteria for Adverse Events (CTCAE). No progress disease was documented after 14 ± 4 weeks.

Discussion

^{223}Ra was shown to be safe and well tolerated, regardless of prior or concurrent exposure to abiraterone, enzalutamide or docetaxel [11]. However, it not yet understood if an earlier setting of abiraterone, enzalutamide and/or when resistance to castration has been established, the ^{223}Ra would be beneficial, especially in patients with high bone tumor burden at the diagnosis of the disease as betide in many countries, including Latin-American countries [2].

This pilot study with off-label use of ^{223}Ra in mHSHGPC patients with multiple painfully bone metastases with concomitant ADT, has shown can be safe and effective, not only in controlling the pain and decrease the need for the intake

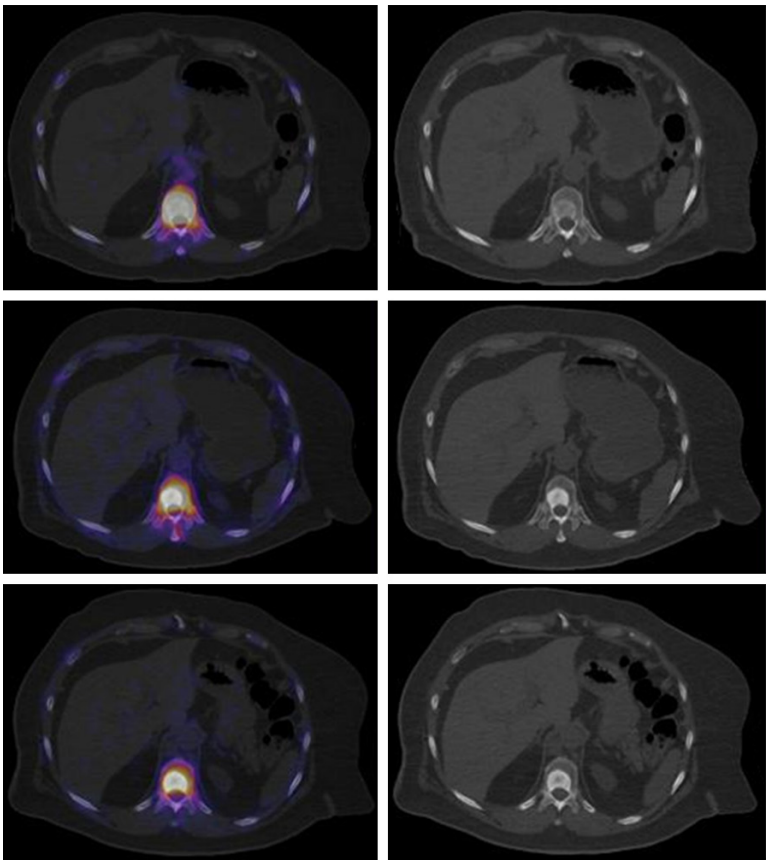

Figure 5. *Top*. Fused axial slice of baseline ^{18}F-NaF-PET/CT and high radionuclide uptake (left), axial slice showed blastic lesion in vertebral body (right). *Middle. D*ecrease focal uptake in blastic lesion (left), important increase of sclerotic component, after 3 cycles of ^{223}Ra is seen. *Lower*. decrease focal uptake in blastic lesion (left), note the increase of sclerotic component, after 6 cycles of ^{223}Ra plus ADT.

of painkillers and opioids; also to decrease biochemical markers linked to the patient's prognosis, such as PSA, LDH and ALP.

Serum biomarkers, such as PSA and bone ALP, are commonly used as early efficacy markers in CRPC and bone metastases; several studies shown that a PSA reduction ≥ 30% from baseline has been shown to correlate more closely with survival than earlier ≥ 50%; however, in the context of mHSHGPC not fully understood [12, 13].

In a recent study by Sartor et al. studied the baseline clinical variables are prognostic for overall survival (OS) in patients with CRPC; they demonstrated that total alkaline phosphatase (tALP), LDH, and PSA at baseline were associated with OS [14].

In addition it has shown that the feasibility of measuring the semi-quantitative changes of ^{18}F-NaF-PET/CT scan using SUVs is able to measure changes not detected by qualitative visual inspection in patients with bone metastases from prostate cancer receiving systemic therapy with ^{223}Ra. Previous reports suggest this method as a tool for measurements of blastic lesions after treatment with ^{223}Ra [15, 16].

Another study by Wenter et al. suggest that ^{223}Ra for primary bone metastases in patients with metastatic Hormone-Sensitive PC after radical prostatectomy is feasible and alleviates pain. ALP, rather than PSA, may be a good marker for assessing treatment response. Meanwhile, bone scintigraphy was performed to assess treatment response not ^{18}F-NaF-PET/CT. Seven of ten patients completed six cycles of ^{223}Ra. Discontinuation was due to leukopenia and lymphopenia, progressive lymph node metastasis or newly diagnosed liver metastasis. Treatment-related adverse events occurred in three patients such as fatigue, abdominal discomfort and nausea. Overall, a median decrease of 28% in ALP and a median decrease of 83% in PSA were noted at follow-up. However, PSA progressed in five patients at follow-up [17].

In our previous study we demonstrated the usefulness and effectiveness of ^{223}Ra in as an aiding agent that can be employed in conjunction with bicalutamide and gosereline to produce excellent results in treating patients with hormone-sensitive PC with symptomatic bone metastases, and the evaluation of response with ^{18}F-NaF-PET/CT in conjunction with PSA and ALP [18]. PET/CT also has the inherent advantage over the conventional ^{99m}Tc-MDP bone scintigraphy of more accurate and absolute quantification of radioactive tracer concentrations, and therefore lends itself to a semi-quantitative approach [19-21]. In addition to being shown to have greater sensitivity and

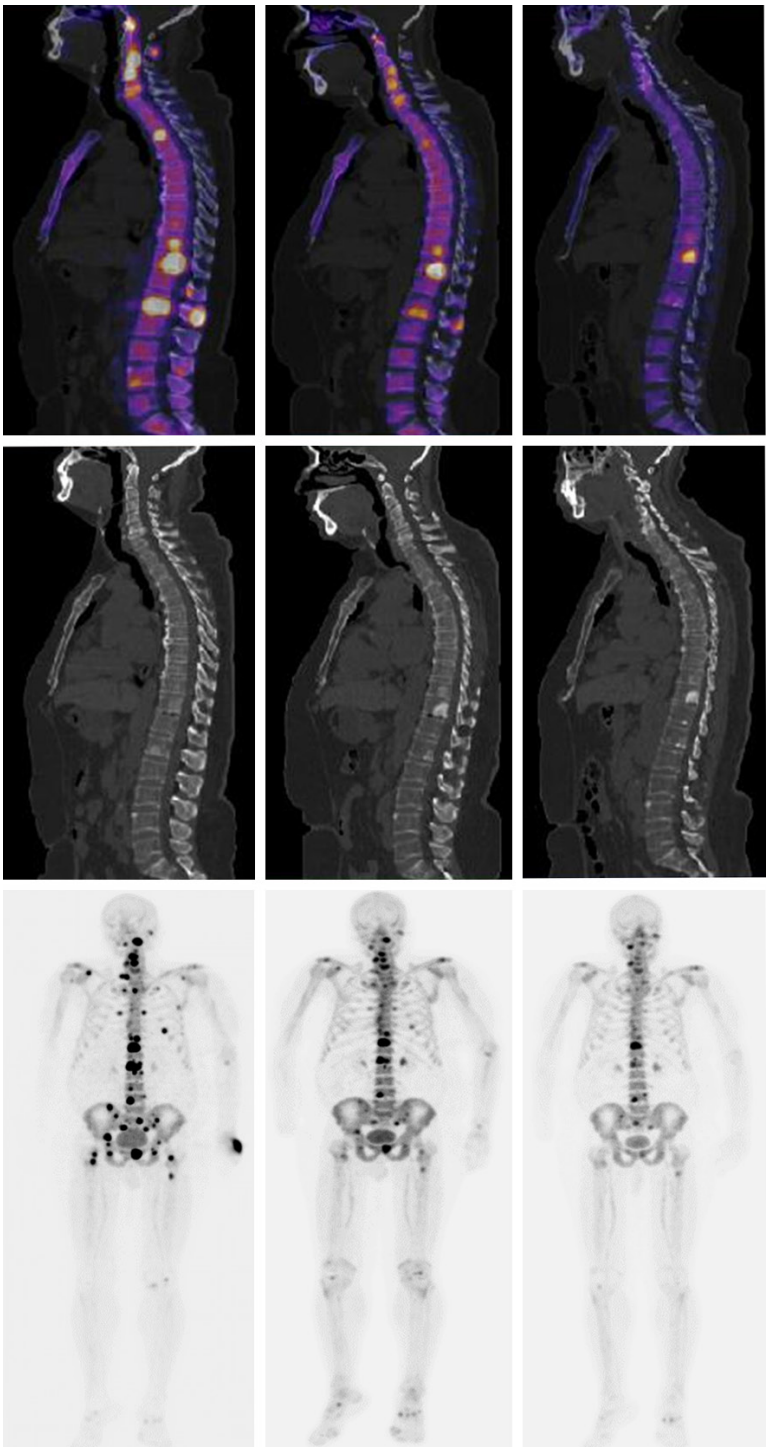

Figure 6. *Top Left*. Fused sagittal slice of baseline ^{18}F-NaF-PET/CT and high radionuclide uptake in multiple vertebral bodies. *Top middle.* Fused sagittal slice ^{18}F-NaF-PET/CT after 3 cycles of ^{223}Ra. *Top Right.* Fused sagittal slice ^{18}F-NaF-PET/CT after 6 cycles of ^{223}Ra plus ADT, note the important osteoblastic activity. *Middle.* Sagittal slices corresponding only a CT baseline, CT after 3 cycles of ^{223}Ra and CT after 6 cycles of ^{223}Ra plus ADT, note the increased sclerotic changes. *Lower Left.* multiple sites of focal high radionuclide uptake that result in metastatic bone disease predominantly blastic type axial skeleton in the MIP ^{18}F-NaF-PET. *Lower middle.* MIP ^{18}F-NaF PET after 3 cycles of ^{223}Ra. *Lower Right*. MIP ^{18}F-NaF-PET after 6 cycles of ^{223}Ra plus ADT, note the important decreased of osteoblastic activity (patient 4).

specificity in detecting metastatic osteoblastic disease [22, 23].

Age, in addition to tumor burden, may be a factor involved in treatment efficacy; in our study, the most long-lived patient (number 7) had a high tumor burden (superscan), and no significant benefit was seen when quantitatively assessed with ^{18}F-NaF-PET/CT, however, if there was an improvement in pain at the end of the 6 cycles. Probably one reason is the low medullary reserve associated with aging. These findings need to be confirmed with a larger cohort of patients.

The principal limitation of this study is due to concomitant administration of ADT, because imaging cannot differentiate whether the findings were due to androgen blockade or to the administration of ^{223}Ra; nevertheless data supporting the efficacy of ^{223}Ra is the significant improvement on pain. The mechanism of action of both ADT plus ^{223}Ra may represent a synergistic effect; molecular imaging can be additionally value in the earlier evaluation of response of this patients [24]. Given the short time of follow-up, no information on overall survival or progression free survival could be obtained.

Despite these limitations, this study demonstrated the off-label use of ^{223}Ra for bone metastatic disease in patients with mHSHGPC at initial diagnosis of the diseases without radical prostatectomy. However, the design of future randomized trials are needed to confirm these findings.

Table 3. Characteristics of patients studied after 6 cycles with Ra-223

Patient	Mean SUVmax (Range)	Mean SUVmax (Range) [% of baseline] After 3 cycles*	Mean SUVmax (Range) [% of baseline] After 6 cycles**	PSA (ng/ml)	ALP (UI/L)	LDH (UI/L)	VAS	Hb (g/dl)	Plt (× 10^3/μL)	Neutrophils (× 10^3/μL)	Leukocytes (× 10^3/μL)
1	91.6 (79.1-144.1)	63.3 (45.4-99.1) [69.1%]	58.1 (40.7-70.3) [63.4%]	0.6	70	145	4	12.5	216	3.7	4.9
2	66.8 (26.9-84.2)	49.3 (18.9-69.7) [73.8%]	19.9 (14.4-49.0) [30%]	5.7	129	148	2	13.1	202	4	5.5
3	58.7 (22.5-76.4)	40.2 (17.2-54) [68.5%]	17.3 (4.1-28.8) [29.5%]	0.13	49	120	1	13.1	300	3.3	4.7
4	81.7 (33.1-91.9)	73.0 (28.6-80.1) [89.3%]	38.7 (14.8-66.2) [47.4%]	1.3	53	230	1	13.1	277	3.9	6.3
5	69.1 (36.9-101.2)	52.9 (31.0-89.7) [76.5%]	27.3 (14.4-49.9) [39.5%]	1.2	119	85	2	9.7	188	2.5	4.1
6	89.7 (53.1-101.6)	70.5 (42.1-88.8) [78.6%]	66.9 (38.7-80.9) [74.6%]	0.9	101	113	2	9.9	283	3.4	3.9
7	96.6 (84.7-155.0)	95.3 (88.3-141.1) [98.6%]	90.9 (80.7–131.7) [94.1%]	2.4	120	134	4	8.8	209	2.9	2.9

*Percentage of declined Mean SUVmax after 3 cycles of Ra-223. **Percentage of declined Mean SUVmax after 6 cycles of Ra-223.

Conclusion

^{223}Ra can be useful in mHSHGPC in concomitant ADT despite to RT palliative¸ in addition we suggest that semi-quantitative ^{18}F-NaF-PET/CT whole body scan as a method to monitor the treatment response in bone metastases following therapy with ^{223}Ra and ADT in conjunction with biochemical markers linked to the patient's prognosis, such as PSA, LDH and ALP.

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Disclosure of conflict of interest

None.

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