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BEST IN PHYSICS (IMAGING): Prospective Control of Prior-Image-Based Reconstruction for Ultralow-Dose CT: Application in Lung Nodule Surveillance

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Control of prior image penalty strength in PIRPLE

$$\hat{\mu}_{PIRPLE} = argmax \ \ L(\mu; y) - \beta_R \, \|\Psi_R\mu\|_1^1 - \beta_P \, \|\mu - T(\mu_P)\|_1^1$$

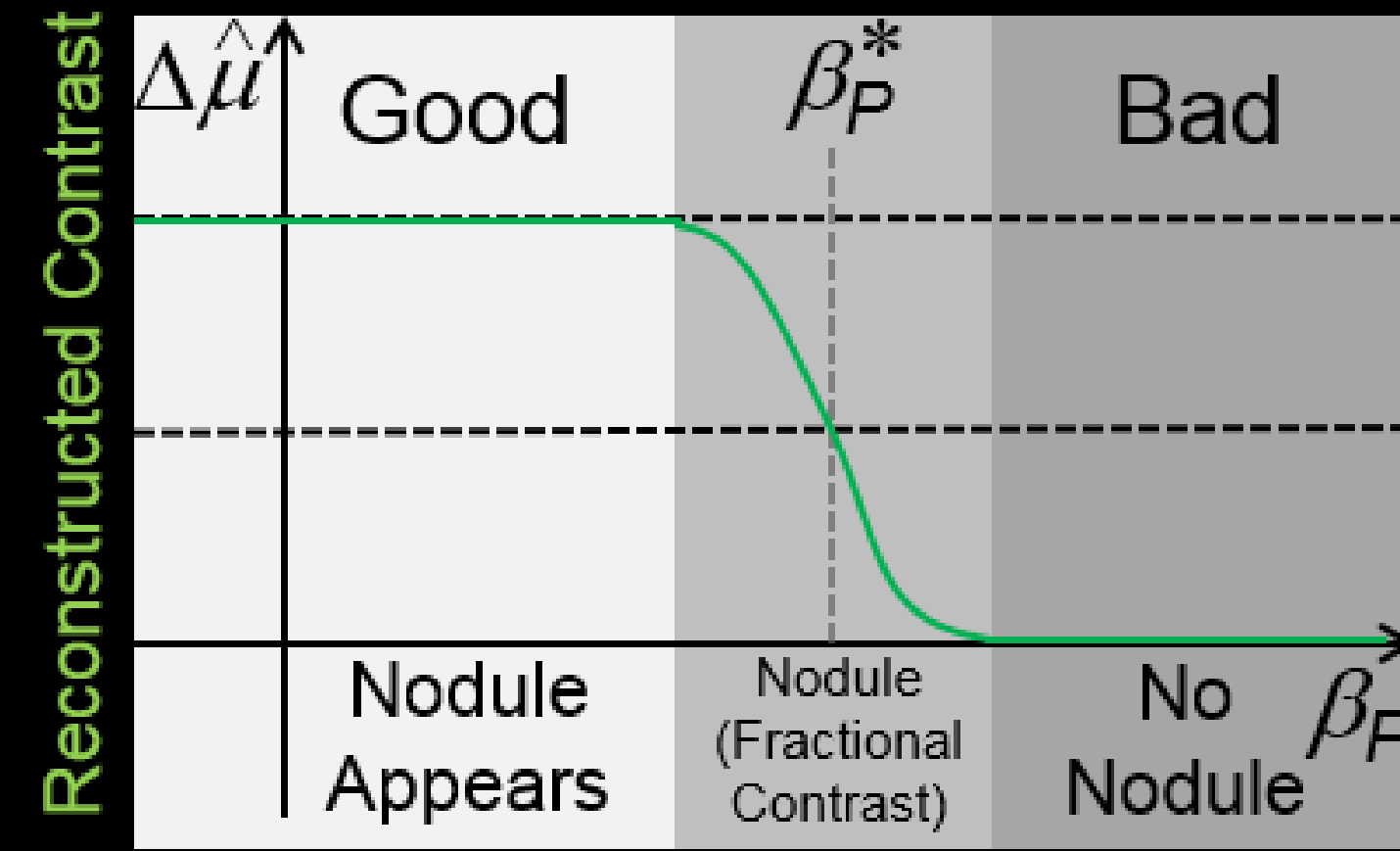Roughness Penalty term

Prior image Penalty term

Fig. 1 illustrates typical behavior for PIRPLE (the reconstructed change intensity versus prior image regularization strength) where the contrast of a lung nodule, found in the current CT data but not found in a prior image. We observed that the nodule contrast is reliably reproduced up to a certain β_P (first plateau, left region), then the contrast abruptly diminishes (middle region), and disappears with higher β_P (right region).

Approximate closed-form solution
(without registration)

$$\hat{\mu} = \arg\max \ L(\mu; y) - \beta_R\|\Psi\mu\|_1 - \beta_P\|\mu - \mu_P\|_1$$
$$\approx \arg\min\|A\mu - l\|_W^2 + \beta_R\|\Psi_R\mu\|_{D_R}^2 + \beta_P\|\mu - \mu_P\|_{D_P}^2$$
$$= (A^TWA + \beta_R\Psi_R^TD_R\Psi_R + \beta_PD_P)^{-1}(A^TWl + \beta_PD_P\mu_P)$$

Derived regularization-bias relationship in the transition region

$$\forall_j \ \ \beta_{P,j}^* = (1 - \gamma)\left[A^TWA\Delta\mu(j)\right]_j$$

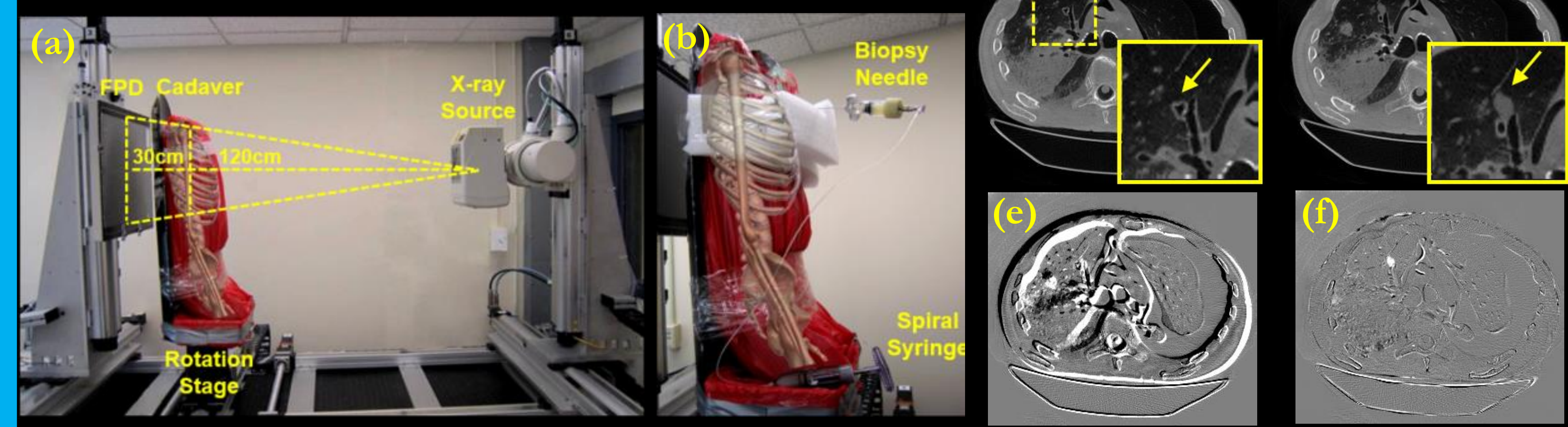## Cadaver study with CBCT testbench

Fig. 2. (a) Cadaver and CBCT testbench; (b) petroleum jelly injected to the cadaver; (c) prior image of the cadaver; (d) current anatomy after petroleum jelly injection and imparted deformations; (e) difference between (c) and (d), indicating deformation between two scans; (f) difference image after a deformable registration, showing the nodule appearance in current anatomy.
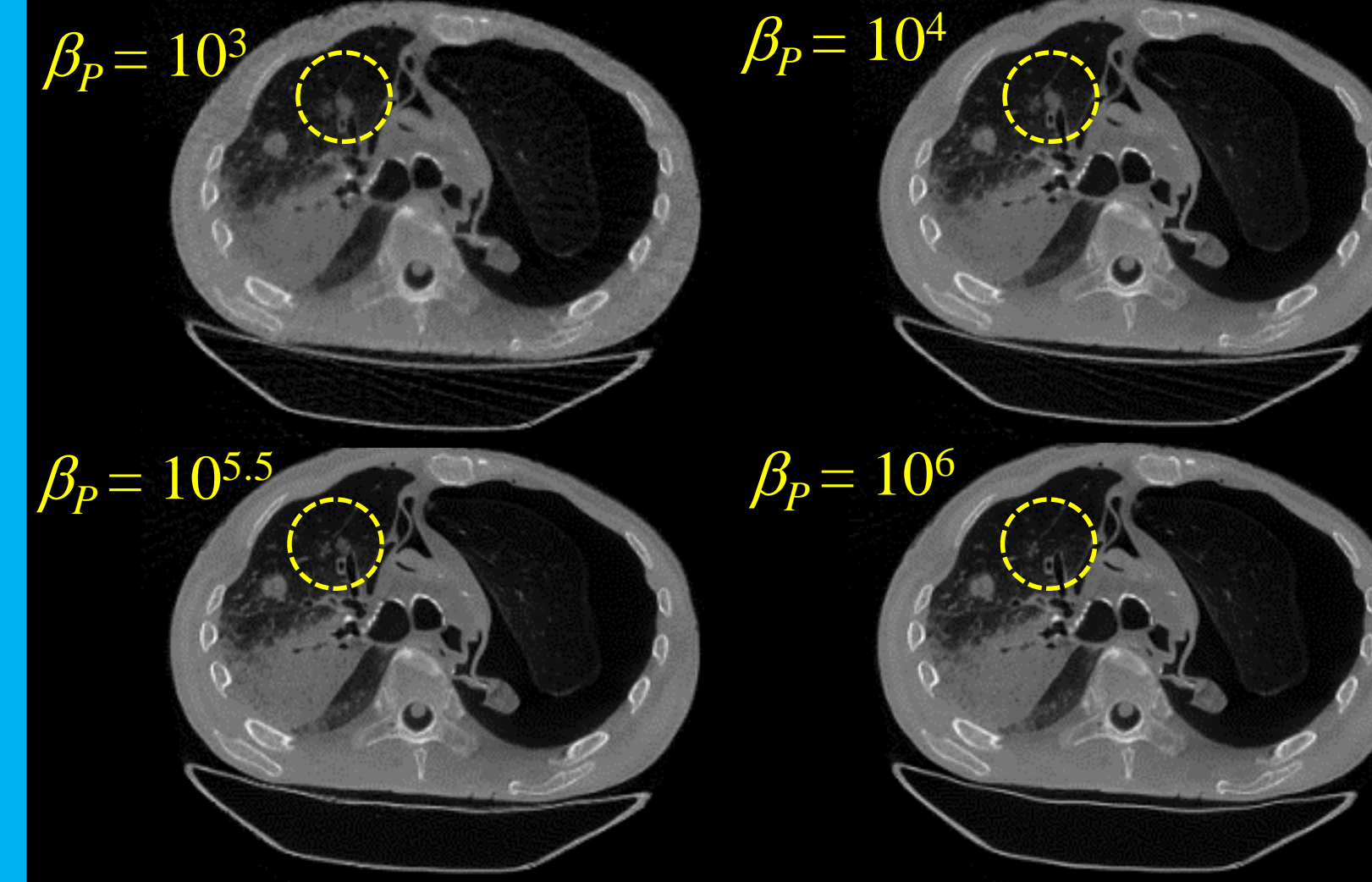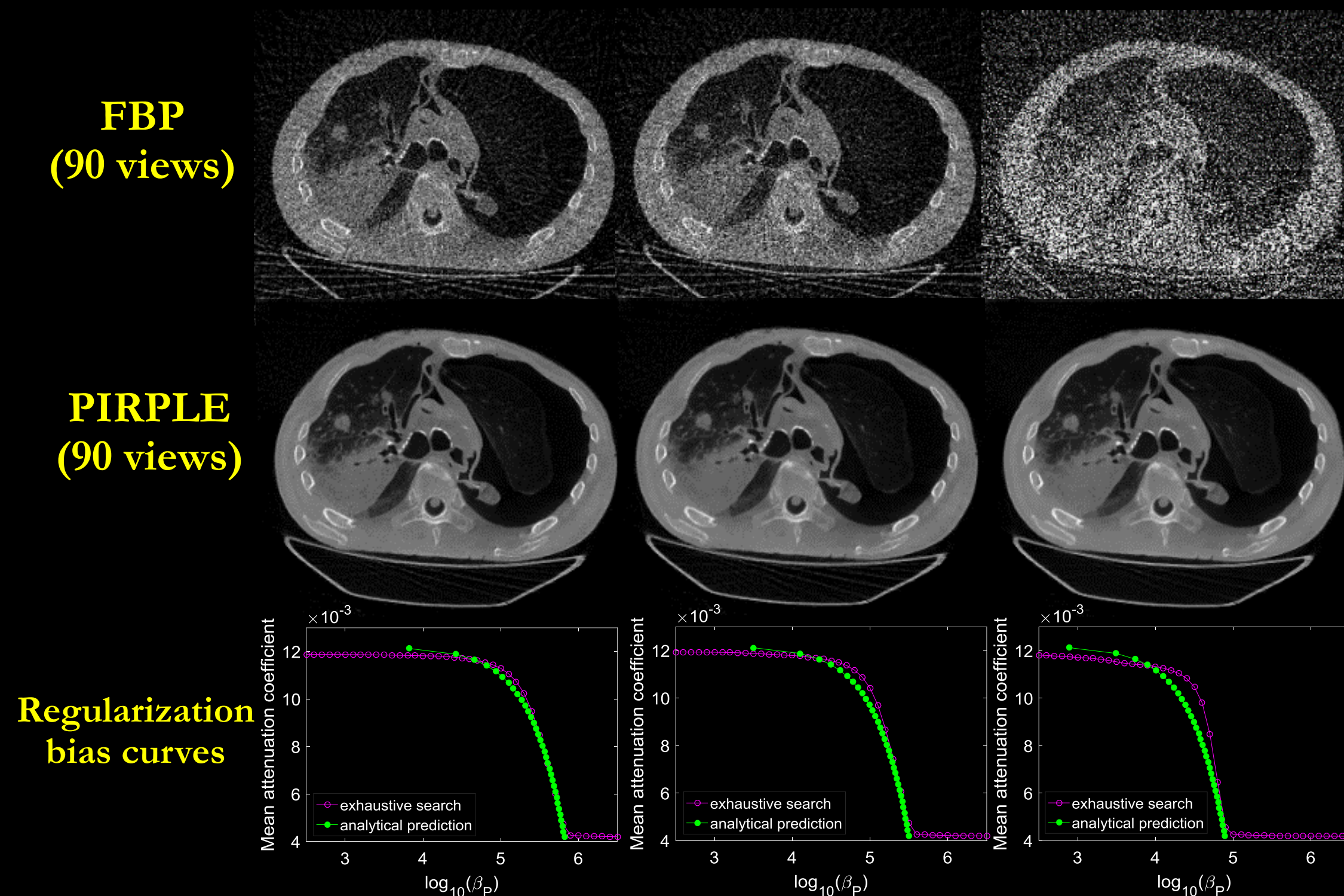
Cadaver study results

$\beta_P = 10^3$ $\beta_P = 10^4$ $\beta_P = 10^{5.5}$ $\beta_P = 10^6$

1.25 mAs/projection 0.6 mAs/projection 0.1 mAs/projection

FBP (90 views)

PIRPLE (90 views)

Regularization bias curves

Fig. 3. PIRPLE reconstructions of the cadaver at four different prior image regularization values. If β_P is too low, image quality suffers; and if β_P is too high, the reconstruction reproduces the prior image which has no nodule. One can observe the trend as in Fig. 1.

NLST data study

$I_0 = 3 \times 10^4$ $I_0 = 1 \times 10^4$ $I_0 = 3 \times 10^3$

FBP (90 views)
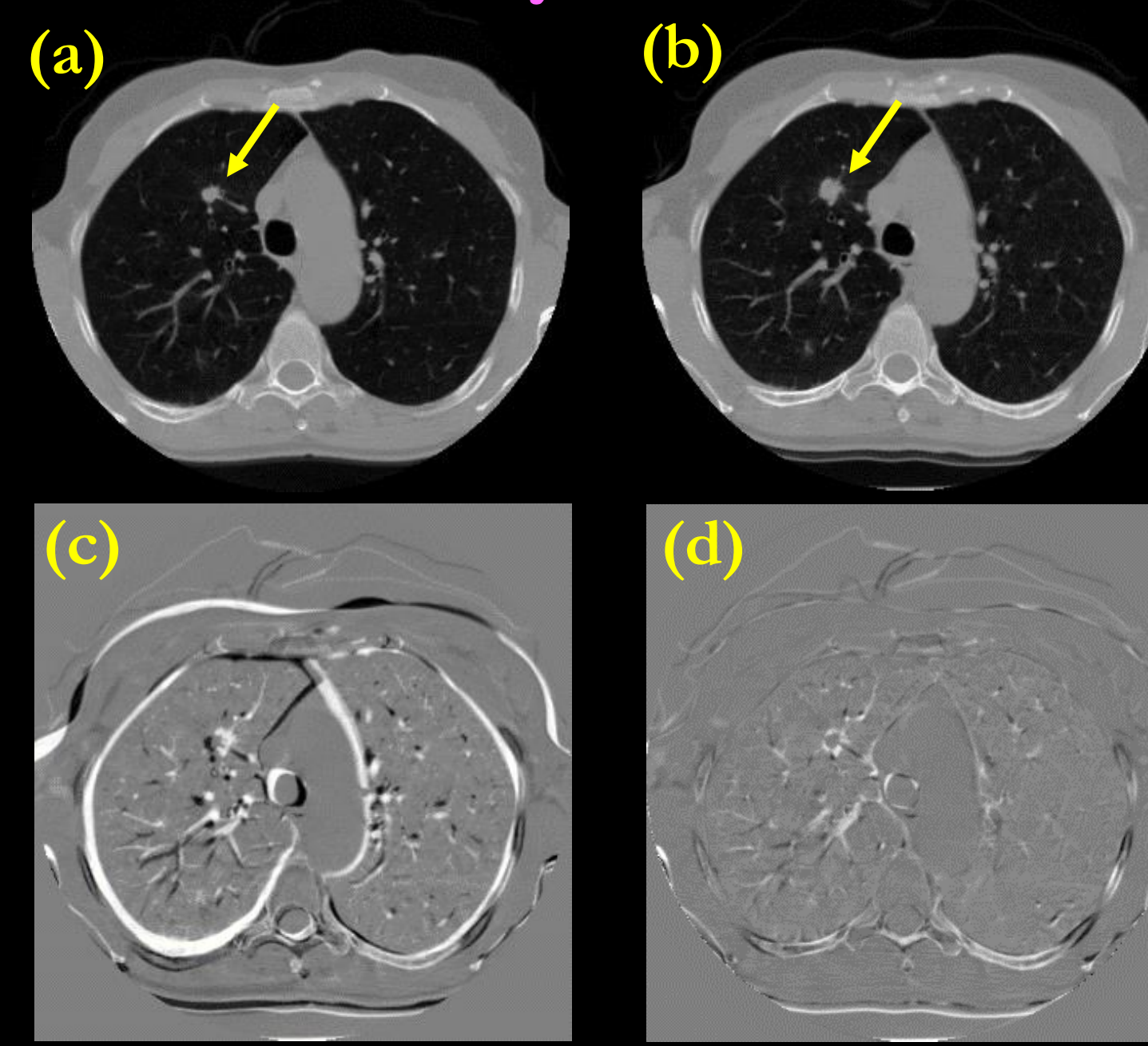
PIRPLE (90 views)

Regularization bias curves

Fig. 4. (a) Prior image with small nodule; (b) current lung anatomy with grown nodule; (c) difference image between (a) and (b), indicating mismatch between two sequential scans; (d) difference image after a deformable registration.