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THE 3D PELVIC INCLINATION CORRECTION SYSTEM (PICS): A UNIVERSALLY APPLICABLE COORDINATE SYSTEM FOR ISOVOLUMETRIC IMAGING MEASUREMENTS

Hypothesis / aims of study
Pelvic organ prolapse (POP) is a downward displacement along the axis of gravity. The study of pelvic floor disorders requires the measurement of organ position in 3D space. So far, no 3D coordinate system has been developed for position-dependent structures such as the pelvis and pelvic organs. Based on the Pelvis Inclination Correction System (PICS) line, which corrects for any movement of the pelvis in the midsagittal plane (1), we propose a universally applicable 3D coordinate system that allows the localization of any point in the pelvis at rest or under dynamic conditions on magnetic resonance images (MRI) in a scanner- and software independent manner.

Study design, materials and methods
In this methodological study, the construction of a moving frame attached to the pelvis is presented, and an application in two patients with POP. For the construction of the reference frame four landmark points are selected. In the sagittal plane the scanner coordinates of the inferior pubic point at the lower border of the symphysis (A) and the sacrococcygeal point (B) are chosen, and in the axial plane the ischial spine points (I_R and I_L) are chosen to stabilize the horizontal plane that runs perpendicular to the plane defined by point A and B. The scanner coordinates of the organ of interest are noted (Fig 1). Origin of the coordinate system is the inferior pubic point (Point A). Three perpendicular axes are then constructed from the positions of the anatomical landmarks in the original scanner coordinate system. In order to achieve this, an initial coordinate system is first created.
Each of the selected points is exported as a row vector, as below.
$$\hat{x} = [x \ y \ z] \qquad (1)$$
Three perpendicular axes are then constructed from the positions of the anatomical landmarks in the original scanner coordinate system, defining the fixed pelvis coordinate system. The vector $\hat{u}$ is calculated as below, pointing from the inferior pubic point (A) to the sacrococcygeal point (B). It is converted to a unit vector (with length 1) by dividing by its own length.
$$\hat{u} = \frac{B - A}{\|B - A\|} \qquad (2)$$
A second vector $\hat{\imath}$ is then constructed from the right (I_R) and left (I_L) ischial spine points, and converted to a unit vector, as below.
$$\hat{\imath} = \frac{I_R - I_L}{\|I_R - I_L\|} \qquad (3)$$
The cross product of these vectors provides the vector $\hat{v}$.
$$\hat{v} = \hat{\imath} \times \hat{u} \qquad (4)$$
Which is then used to generate the vector $\hat{w}$.
$$\hat{w} = \hat{u} \times \hat{v} \qquad (5)$$
These three orthogonal vectors ($\hat{u}$, $\hat{v}$, $\hat{w}$) represent the orientation of the initial coordinate system.
$$R_{Init} = [\hat{u}' \quad \hat{v}' \quad \hat{w}'] \qquad (6)$$
In order to align this with the desired reference frame, this must be rotated in the sagittal plane; a rotation of 34° around the $\hat{w}$ axis that is the standardized inclination of the pelvis.
$$R_{Rot} = R_{34°\hat{w}} \times R_{Init} \qquad (7)$$
Finally, a transformation matrix is constructed from the rotated axes and the origin (point A) as below.
$$T = \begin{bmatrix} R_{Rot} & A' \\ 0 & 1 \end{bmatrix} \qquad (8)$$
In order to determine the position of any point within the pelvis relative to this coordinate frame, the transformation matrix is inverted and the selected point multiplied.
$$X_{PPS} = T^{-1} \times X \qquad (9)$$
Thus resulting in the transformation of the organ position from scanner coordinates into the pelvis coordinate system.

Results
The feasibility and applicability of the moving frame was evaluated using MRI datasets from two patients in a static supine position and dynamic MRI.
Clinically the 29 year-old Gravida II, Para I has a uterus descent to the hymen (POP-Q II). Control measurements completed in single 2D slices revealed a distance of 15 mm from the cervix to the PICS line; the developed pelvis positioning coordinate system returned a distance of 15.19 mm above the PPS horizontal plane.
The second patient was a 65-year-old woman with a cystocele and uterus descent (POP-Q III) undergoing defecography MRI for stool outlet symptoms. The change of the cervix location at rest and maximum Valsalva was registered on dynamic MRI. At rest, 2D control measurements revealed an organ to PICS line distance of 55 mm, with a value of 54.77 mm above the PPS horizontal plane observed when utilizing the 3D technique. At strain an organ to PICS line distance of 18 mm was observed, with an organ position 19.11 mm below the PPS horizontal plane calculated by the 3D PPS technique.

Interpretation of results
The PPS rigid 3D coordinate system allows physicians to quantify the position of any pelvic organs, as well as the location and magnitude of muscular or ligamentous defects lying *outside from the midsagittal plane*, in an easily applicable and reliable way. This standardized, rigid coordinate system also corrects for common patient positioning errors, which can be exacerbated by Valsalva.

For the future, we anticipate that data obtained from the proposed rigid 3D coordinate system will lead to clinically relevant advances in overall understanding of pelvic anatomy. This will move the field vertically to study the physiologic range of organ location as well as defects on the pelvic side wall, birth-related pelvic floor injuries and the comparison of outcomes between different surgical collectives

Concluding message
The developed approach makes quantitative assessment of pelvic organ position in the proposed 3D coordinate system feasible.
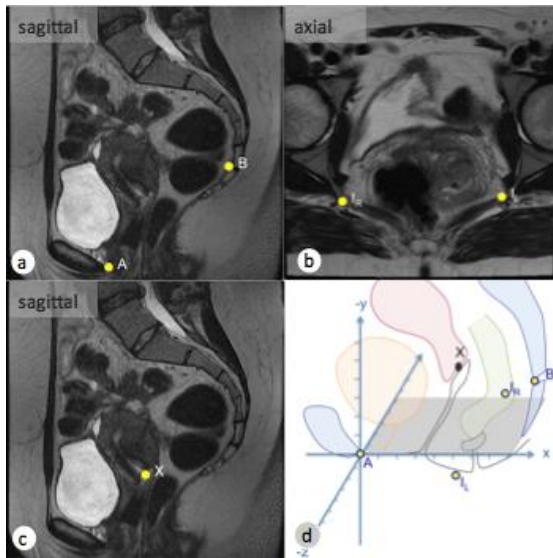
Figure 1:
Point Placement. a) and b) defining for bony landmark points to set up the 3D coordinate system. Consistent bony landmark points are in a) midsagittal slide: point A, inferior pubic point; B, anterior border of the sacrococcygeal point; b) axial slide: I_R, right ischial tuberosity; I_L, left ischial tuberosity. In c) the cervical os is marked with point X. d) a rigid coordinate system is set up to calculate the coordinates of point X (cervix, black dot), expressed as coordinates (x/y/z) in reference to point (0/0/0) at the inferior pubic point. The height of the organ corresponds to the value of the coordinate y.

References

1. Betschart C, et al. On pelvic reference lines and the MR evaluation of genital prolapse: a proposal for standardization using the Pelvic Inclination Correction System. International Urogynecology Journal. 2013;24(9):1421-8