INTRODUCTION

Presently, uterine cervix carcinoma represents a significant public health problem. Despite the longer survival of patients because of earlier diagnoses and more effective therapies, this disease still remains as the leading cause of cancer-related death of women in the majority of developing countries. Cervical carcinoma is a slow-growing disease, usually invading the vagina and the paracervical space along the parametrium and uterosacral ligaments. Also, bladder, rectum, pelvic and paraaortic lymph nodes may be invaded. The pattern of pelvic dissemination of cervical carcinoma restricts the utilization of surgical treatment for early stages of the disease, given the lack of a safety margin in the resection of tumors which may have already affected the paracervical space.

The staging recommended by International Federation of Gynecology and Obstetrics (FIGO) is widely adopted both for therapy planning and post-therapy follow-up, however it has shown to be inaccurate in the estimation of the actual tumor extent.

Additionally, the FIGO staging system does not express the real extent of the disease and does not include important prognostic factors such as tumor volume, stromal invasion and lymph node involvement.磁共振在宫颈癌分期中的应用

磁共振成像技术在宫颈癌分期中的应用使得早期的肿瘤可以被准确地分期，从而有助于制定更有效的治疗方案。此外，磁共振成像技术还可以用于监测肿瘤的复发和预测预后的准确度。
not take into consideration relevant prognostic factors such as the tumor volume, vascularization, endophytic or exophytic growth, stromal invasion and lymph nodes involvement\textsuperscript{(3,4)}. Considering this flaw, the FIGO Committee on Gynecologic Oncology started recommending that the definite staging is based on the surgeon’s and pathologist’s intraoperative findings (Figure 1)\textsuperscript{(5)}.

In cases where cervical carcinoma is locally advanced (above IIb), the majority of specialized centers have opted for exclusive radiotherapy or radiotherapy in association with chemotherapy. Therefore, the clinical finding that could not be intraoperatively confirmed should be based predominantly on highly accurate studies. However, in developing countries, basic imaging equipment is not always widely available in health services; so the gynecological examination ends up being the main alternative for staging of cervical carcinomas. The involvement of the parametrium evaluated by rectal examination is a parameter which frequently characterizes a locally advanced carcinoma\textsuperscript{(6)}. Mistakes may occur, especially due to underestimation of the disease extent as a consequence of limitations of the clinical-gynecological examination\textsuperscript{(7)}.

**MAGNETIC RESONANCE IMAGING**

Magnetic resonance imaging (MRI) can evaluate the actual extent of the disease because of its high spatial and contrast resolution for pelvic tissues and organs. Some advantages of MRI are short acquisition time with multiplanar images, comfort for the patient, absence of ionizing radiation, and, mainly, the high reproducibility in the evaluation of musculotendinous structures in the pelvis which are of great relevance in the parametrium evaluation\textsuperscript{(8)}.

T2-weighted images provide excellent details of the cervical anatomy and normal uterus, besides identifying the primary tumor and its extent. The normal cervical stroma presents a low density signal on this sequence, and about 95% of tumors of uterine cervix appear as slightly hyperintense masses in relation to the surrounding stroma\textsuperscript{(9)} (Figure 2). Pre-invasive lesions of uterine cervix carcinoma cannot be identified on T2-weighted images, but may be described as an area of marked early impregnation in the arterial phase of MRI dynamic studies\textsuperscript{(10)}.

Prognostic parameters influencing in an appropriate therapy choice, and which may be evaluated by means of gynecological examination, can be evaluated by MRI with a good cost-effectiveness ratio, considering that patients with cervical cancer submitted to MRI as the initial staging method, require less tests or procedures in comparison with those submitted to a traditional staging method\textsuperscript{(11,12)}.

As a matter of fact, MRI has shown a better accuracy than the clinical examination and computed tomography (CT) as staging methods, particularly in the parametrical evaluation. Comparative studies of the three methods (MRI, CT and clinical examination) have demonstrated 92% accuracy for MRI compared with 78% for clinical examination, and 70% for CT\textsuperscript{(13)}. With the arrival of new turbo sequences and phased-array coils, sensitivity reported for parametrial invasion was 100\%\textsuperscript{(14)}. Other authors highlight a 98% negative predictive value for parametrial invasion in T2-weighted turbo spin-echo (TSE) and short tau inversion recovery (STIR) sequences\textsuperscript{(15,16)}.

The correlation between uterine cervix carcinoma staging proposed by FIGO and MRI findings is described in Table 1\textsuperscript{(17)}.

**Examination technique**

MRI for staging of uterine cervix tumors should cover from the plane passing...
through the inferior renal pole to the vulva, including the paraaortic and pelvic regions. The anterior saturation band should be utilized as a routine to reduce respiratory and peristaltic artifacts. On the other hand, the posterior saturation band is dispensable. The use of antiperistaltic agents four to six hours before the examination also is recommended to reduce artifacts resulting from intestinal peristalsis\(^{(3,10)}\). The phased-array coil improves the signal-noise ratio, allowing the acquisition of more detailed images than the formerly utilized body coils, and, consequently improving the imaging resolution. However, body coils may be useful for obese patients with a very protuberant abdomen, or for retroperitoneal evaluation\(^{(18)}\). The utilization of endorectal and endovaginal coils has been described as means to produce high-signal images, but, despite the high degree of definition, their use is limited because of the lack of consensus about their advantages over the phased-array coils\(^{(19)}\).

The staging of uterine cervix tumors requires three planes in the T2-weighted TSE sequence in high resolution, i.e., 512 matrix, small field-of-view (FOV), sections always < 5 mm (preferably 3–4 mm), with gap of zero, all of them obtained in the axial plane. Additionally, a T1-weighted TSE sequence in the true axial plane of the pelvis with large FOV is essential for acquisition of a global pelvic view\(^{(17)}\).

Sagittal images are useful for demonstrating the relation between tumor and cervix, uterine body, vagina and adjacent organs such as bladder and rectum. On the other hand, axial images are relevant for detection of parametrial and pelvic wall invasion, ureteral and lymph nodes involvement. The coronal plane, in conjunction with the sagittal and axial planes, is useful in the parametral evaluation, and particularly necessary for measurement of the tumor volume (Figure 3).

T2-weighted TSE is the sequence of choice in the evaluation of lymph nodes involvement, since in this sequence, muscles and vessels appear hyperintense, differently from lymph nodes. Fat suppression improves even more the identification of structures or lesions surrounded by adipose tissues like parametrium and lymph nodes\(^{(15,20)}\) (Figure 4).

Many times, the use of contrast is not necessary in the staging, since, in most of cases, precontrast sequences provide the necessary information. Besides, dynamic sequences frequently underestimate the tumor volume and the depth of the stromal invasion, and should not be utilized for these purposes\(^{(21)}\). However, the use of contrast agent may be useful for facilitating the identification of fistulous tracts in advanced diseases or in the post-therapy follow-up\(^{(10)}\).

### TUMOR GROWTH PATTERNS

The tumor arises in the cervical canal and extends peripherally towards the cervical stroma, progressively replacing it. A full-thickness stromal invasion may occur, and, by contiguity, a parametrial invasion (IIb). Cervical canal obstruction is usual, and frequently causes the endometrial cavity to be distended with blood, serous fluid or purulent material\(^{(22)}\) (Figure 5).

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**Table 1** Correlation between FIGO staging of uterine cervix cancer and MRI findings\(^{(17)}\).

<table>
<thead>
<tr>
<th>Stage</th>
<th>MRI T2-weighted sequence</th>
</tr>
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<tbody>
<tr>
<td>Ia</td>
<td>Microinvasor</td>
</tr>
<tr>
<td>Ib</td>
<td>Invasive, confined to the cervix</td>
</tr>
<tr>
<td>Ib1</td>
<td>Clinically visible lesion $\leq$ 4 cm</td>
</tr>
<tr>
<td>Ib2</td>
<td>Clinically visible lesion &gt; 4 cm</td>
</tr>
<tr>
<td>Iia</td>
<td>Tumor invades the upper vaginal third, but does not affect the lower vaginal third</td>
</tr>
<tr>
<td>Iib</td>
<td>Tumor invades the parametrium, but not the pelvic wall neither the lower vaginal third</td>
</tr>
<tr>
<td>Iiia</td>
<td>Involvement of the lower vaginal third, without affecting the pelvic wall</td>
</tr>
<tr>
<td>Iiib</td>
<td>Pelvic wall involvement or hydronephrosis</td>
</tr>
<tr>
<td>IVa</td>
<td>Tumor invades the bladder or rectum mucosa</td>
</tr>
<tr>
<td>IVb</td>
<td>Distant metastasis</td>
</tr>
</tbody>
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**Figure 2. A:** Sagittal T2-weighted TSE sequence, hyperintense uterine cervix tumor. Part of the (hypointense) cervical stroma is intact. Preserved vaginal canal (stage Ib). **B:** Sagittal T2-weighted TSE sequence, slightly hyperintense tumor in the posterior portion of the uterine cervix, extending to the upper vaginal third (stage IIa).

**Figure 3.** Sagittal images are useful for demonstrating the relation between tumor and cervix, uterine body, vagina and adjacent organs such as bladder and rectum. On the other hand, axial images are relevant for detection of parametrial and pelvic wall invasion, ureteral and lymph nodes involvement. The coronal plane, in conjunction with the sagittal and axial planes, is useful in the parametral evaluation, and particularly necessary for measurement of the tumor volume.

**Figure 4.** T2-weighted TSE is the sequence of choice in the evaluation of lymph nodes involvement, since in this sequence, muscles and vessels appear hyperintense, differently from lymph nodes. Fat suppression improves even more the identification of structures or lesions surrounded by adipose tissues like parametrium and lymph nodes.

**Figure 5.** Many times, the use of contrast is not necessary in the staging, since, in most of cases, precontrast sequences provide the necessary information. Besides, dynamic sequences frequently underestimate the tumor volume and the depth of the stromal invasion, and should not be utilized for these purposes. However, the use of contrast agent may be useful for facilitating the identification of fistulous tracts in advanced diseases or in the post-therapy follow-up.
Figure 3. A: Axial T2-weighted TSE sequence, tumor completely replacing the cervical stroma in its largest anteroposterior diameter. B: Coronal T2-weighted TSE sequence of the same patient showing the largest latero-lateral diameter of the tumor. Note the bilateral adenomegalies. C: Sagittal T2-weighted TSE sequence, largest craniocaudal diameter of the tumor. Preserved signal of the bladder mucosa.

Figure 4. A: Axial T2-weighted TSE sequence, the same patient in Figure 3 in an uppermost plane. The arrows indicate bilateral adenomegalies, with a slightly hyperintense signal similar to the cervical tumor. B: Axial T2-weighted TSE sequence with fat suppression. The arrows indicate the same adenomegalies as A, more evident in this sequence.

Tumors extending into the uterine cavity are associated with a worst prognosis and higher prevalence of distant metastases. Clinically, tumors with endophytic growth are difficult to be measured, since the largest component cannot be directly visualized and evaluated in a gynecological examination. The clinical evaluation of exophytic tumors is easier, but MRI facilitates the identification of a possible vaginal invasion.

Evaluation of parametrium and pelvic wall

The parametrium is the connective tissue between the layers of the broad ligament. Medially it is contiguous with the uterus, cervix and proximal vagina; extending laterally to the pelvic wall. Inferiorly, it is nearly the cardinal ligament. It is predominantly consisted of fat through which run uterine vessels, nerves and lymphatic vessels.

Parametrial invasion (above IIb) is a significant prognostic factor influencing in the diagnosis and therapeutic choice. On T2-weighted sequences, the interface between the normal cervical stroma and the parametrium appears like a hypointense ring or halo surrounding the cervix. A preserved hypointense halo represents a high negative predictive value for parametrial invasion. The indicator of parametrial invasion is the segmental interruption or complete absence of this halo in the interface between the cervical stroma and the parametrial fat, or yet, the clear protrusion of the tumor into the parametrium. Some authors correlate the complete replacement of the cervical stroma and the tumor extension into the uterine body with the parametrial invasion. In these cases, 94% of the parametrium is invaded, with direct relation between the size of the tumor and the parametrial involvement. Loss of parametrial fat may be an indicator of invasion, but this is a non-specific sign, since peritumoral inflammation also
MR imaging in the staging of cervical cancer

Figure 5. A: Sagittal T2-weighted TSE sequence, hyperintense tumor completely replacing the uterine cervix stroma and obstructing the cervical canal, causing distension of the endometrial cavity filled with a highly hyperintense fluid. B: Sagittal T2-weighted TSE sequence, tumor completely replacing the uterine cervix stroma; so there is no accumulation of fluid inside the endometrial cavity.

The sign of vaginal involvement is better characterized on high-resolution T2-weighted sequences, showing the segmental interruption of the normal hypointense signal of the vaginal wall, or yet a hyperintense vaginal thickening (tumor), or the mass itself in contiguity with the vaginal wall (Figure 8). Vaginal invasion corresponds to stage IIa; when this invasion extends up to the lower vaginal third, corresponds to stage IIIa.

Vaginal involvement

MRI is highly sensitive in the detection of vaginal invasion, with 93% accuracy. The sign of vaginal involvement is better characterized on high-resolution T2-weighted sequences, showing the segmental interruption of the normal hypointense signal of the vaginal wall, or yet a hyperintense vaginal thickening (tumor), or the mass itself in contiguity with the vaginal wall (Figure 8). Vaginal invasion corresponds to stage IIa; when this invasion extends up to the lower vaginal third, corresponds to stage IIIa.

Parametrial invasion up to the pelvic wall (IIib) is diagnosed when the tumor cannot be separated from the pelvic wall at clinical examination. At MRI, this diagnosis is made when the distance between the tumor and the pelvic wall is < 3 mm, or when T2-weighted sequences show partial or complete loss of a normal hypointense signal of the pelvic wall musculature (piriform muscle, internal obturator muscle, levator ani muscle or coccygeal muscle) (Figure 7).

Parametrial invasion may result in loss of fat simulating invasion.

Contrast-enhanced T1-weighted sequences have demonstrated higher accuracy than the T2-weighted in parametrial evaluation (10) (Figure 6). In cases where the tumor extends into the parametrium it may reach the ureter, causing hydronephrosis (IIib). Hydronephrosis associated with mass in the uterine cervix are specific signs of parametrial invasion (12).

Vaginal involvement

MRI is highly sensitive in the detection of vaginal invasion, with 93% accuracy. The sign of vaginal involvement is better characterized on high-resolution T2-weighted sequences, showing the segmental interruption of the normal hypointense signal of the vaginal wall, or yet a hyperintense vaginal thickening (tumor), or the mass itself in contiguity with the vaginal wall (Figure 8). Vaginal invasion corresponds to stage IIa; when this invasion extends up to the lower vaginal third, corresponds to stage IIIa. Additionally, the use of intravaginal ultrasonographic gel during the MRI acquisition is recommended to distend and fill the cavity with a highly hyperintense material on T2-
Figure 7. A: Axial illustration of the pelvis showing a tumor restricted to the cervix, with no sign of parametrial invasion (stage I). B: Axial illustration of the pelvis showing a tumor invading the parametrium, without reaching the pelvic wall or right ureter (stage IIb). C: Axial illustration showing cervical tumor invading the parametrium and reaching the right ureter (stage IIIb). D: Axial illustration showing cervical tumor invading the parametrium and reaching the pelvic wall (stage IIIb). E: Axial T2-weighted TSE sequence showing a cervical tumor involving the urethra, and extending up to the pelvic wall with alteration of the ischium signal (arrow). F: An uppermost image of the same sequence clearly showing parametrial invasion (arrow).

sequences). This procedure improves the sensitivity in the evaluation of the vaginal invasion. About 20 ml of gel applied at the moment of the examination are sufficient (10).

Lymph node involvement

Several studies have demonstrated the significance of the lymph node involvement as a factor of worsening in the survival prognosis of women affected by uterine cervix tumor (3, 26). There are three drainage routes from the cervical lymph nodes through which the tumor propagates (Figure 9): the lateral route, along the external iliac vessels; the hypogastric route, along the internal iliac vessels; and the presacral route, along the uterosacral ligament. All of the three routes drain into the common iliac lymph nodes, through which the tumor may reach the paraaortic lymph nodes. Generally, the paracervical and parametrial lymph nodes are the first to be affected, followed by the obturator lymph nodes and, subsequently, the external and internal iliac lymph nodes (27).

T2-weighted are the sequences of choice for evaluation of pelvic lymph nodes, since in these sequences vessels and musculature become hypointense, facilitating the differentiation from lymph nodes which are slightly hyperintense on T2-weighted sequences (Figure 10). T2-weighted TSE fat suppressed sequences allow the suppression of the adipose tissue surrounding the lymphatic vessels, improving the accuracy in the detection of pelvic adenomegalies (12) (Figure 11). Up to the present moment, the suspicion of lymph node metastasis by means of MRI is limited to the increase in the size of the lymph node. Lymph nodes > 10 mm in axial diameter are considered as abnormal. Also, some higher limits are suggested for determined specific sites, as follows: for lymph nodes in the internal iliac chain, 7 mm; for common iliac lymph nodes, 9 mm; and for external iliac lymph nodes, 10 mm. Positron emission tomography with fluoro-deoxy-D-glucose (PET-FDG) seems to offer higher specificity than MRI for enlarged
pelvic lymph nodes\(^{(3)}\). When lymph node central necrosis is identified, the positive predictive value for malignancy is 100%. It has been already demonstrated that lymph nodes with necrosis or signal intensity similar to the tumor presented worst prognosis. The diagnosis of lymph node necrosis may improve with the use of endovenous contrast\(^{(25,28)}\).

Most recently, improvement has been demonstrated in the MRI sensitivity for detection of metastatic lymph nodes in uterine cervix tumors, utilizing a new type of lymph node-specific contrast agent called ferumoxtran-10, with nanoparticles of iron oxide (USPIO). However the utilization of this contrast agent is not a consensus yet\(^{(29)}\).

Considering that the FIGO staging system does not take the lymph nodes involvement into consideration, the detection of enlarged pelvic lymph nodes on MRI corresponds to stage IIIb, as well as the diagnosis of enlarged paraaortic lymph node corresponds to stage IVb\(^{(12)}\).

**Invasion of bladder and rectum**

Invasion of bladder or rectum (IVA) may be difficult to be detected only by a physical examination. MRI has shown to be a reliable method for detection of bladder invasion with 83% sensitivity, specificity near 100%, and 99% accuracy. When the bladder presents invaded by the tumor, its wall, which normally is hypointense, shows a focal or diffuse area with increase in the signal intensity on T2-weighted sequences, or simply a vegetating mass into the lumen is observed\(^{(16,30)}\). For defining the bladder invasion, it is important to observe that signal alteration is present both for the bladder muscle and mucosa, otherwise the tumor may be just contiguous to the bladder\(^{(4)}\). Other indicative signs of invasion are hyperintensity on the internal surface of the posterior wall, nodularity or irregularity in the bladder wall (Figure 12).

On the other hand, the vesico-ureteral junction is poorly evaluated because of the difficult visualization of a non-dilated ureter on MRI.

Direct invasion of the ureter is not frequent, however, in the setting of ureter invasion, a tumor extension is observed along the uterosacral ligaments. Findings, usu-
ally, are: focal thickening or segmental interruption of the hypointense signal on the anterior rectal wall.

FINAL CONSIDERATIONS

Even though MRI is not utilized by the majority of oncology services for staging uterine cervix tumors, and, up to this moment, it has not been officially approved by FIGO yet, it is the best imaging method in terms of accuracy for assessment of tumors, and plays an essential role in the therapeutic planning and follow-up.

MRI has shown to be better than the clinical examination, and, when utilized as the initial staging method, reduces the number of invasive procedures and radiological studies such as urography, cystoscopy and rectosigmoidoscopy, with lower cost for the management of the disease. Additionally, the correct assessment of the tumor extent and volume allows optimizing the planning of the fields for external pelvic radiotherapy and brachytherapy.

A recent study has demonstrated that the MRI-aided radiotherapy planning may reduce the possibility of geographic errors as compared with the conventional radiotherapy planning. It is important that the radiologist interpreting a pelvic MRI for uterine cervix tumor, is familiarized with the findings and, mainly, provides information regarding tumor volume, invasion of parametrium, vagina and adjacent organs, besides indicating the tumor growth type and lymph nodes involvement.

Acknowledgments

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