We investigated the relationship of the inferior gluteal nerve to gluteus maximus by dissecting the muscle in 12 fresh-frozen and formalin-treated cadavers. The anatomy was recorded using still digital photography. The course of the inferior gluteal nerve was carefully traced and was noted to enter the deep surface of gluteus maximus approximately 5 cm from the tip of the greater trochanter of the femur. The susceptibility of the nerve to injury during a posterior approach to the hip may be explained by its close relationship to the deep surface of gluteus maximus. It is easily damaged before it has been seen if the muscle is split and parted more than 5 cm from the tip of the greater trochanter of the femur. We suggest that a modified posterior approach be used to expose the hip to avoid damage to this nerve.

Injuries to peripheral nerves occur in 0.5% to 8% of patients undergoing total hip replacement. Previous studies have focused on injury to the femoral nerve, the obturator nerve and the sciatic nerve and its branches. The incidence of damage to the inferior gluteal nerve after replacement of the hip is still uncertain. Peripheral nerve injury may occur during operations on the hip as a result of operative trauma associated with stretching and retraction of the nerve, damage to the neurovascular bundle by methylmethacrylate, dislocation of the hip, haemorrhage or the formation of subfascial haematoma.

In a study conducted by Abitbol et al, of 45 patients who had a lateral approach for a total hip replacement, 35 had abnormal electromyographic findings in the muscles innervated by the superior or inferior gluteal nerves. In ten other patients who had a posterior approach, nine had abnormal electromyographic findings in inferior gluteal innervated muscles and eight of the ten also had abnormalities in superior gluteal innervated muscles. They suggested that abnormalities of gait after the operation may be due to injury to these nerves. In another study, Perron et al concluded that the reduction in walking speed and persistently abnormal gait, sometimes seen in patients one year after THR, were associated with a decrease in the extensor moment with a resultant decrease in the range of extension of the hip and a reduction in the abductor moment.

Various surgical approaches to the hip including the medial, anterior, lateral and posterior, have been studied. The posterior approach has been assessed most widely and is perhaps the most frequently used, but it is also the one most likely to be associated with damage to the inferior gluteal nerve since this structure is not usually seen.

Few studies have focused on damage to the inferior gluteal nerve during hip replacement. Our study aimed to understand the close relationship of gluteus maximus to the inferior gluteal nerve in order to be able to expose the hip posteriorly without damaging this nerve.

Materials and Methods
We obtained 12 cadaver buttocks from a local mortuary. All the specimens were either formalin-treated or fresh-frozen. The latter were allowed to thaw overnight. A skin incision was made around the borders of gluteus maximus. The skin flap was raised and reflected posteriorly. Subcutaneous fat was carefully removed to reveal the underlying muscle. The posterior superior iliac spine and the tip of the greater trochanter of the femur were identified and marked.

In order to examine the relationship between the deep surface of gluteus maximus and the inferior gluteal nerve, the muscle was dissected off its origin from the wing of the ilium with release of its insertion on the iliotibial tract and the gluteal tuberosity of the femur. All of gluteus maximus was then reflected downwards and laterally or medially in order to identify the nerve. The passage of

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the inferior gluteal nerve as it emerged below the piriformis and made its way to the deep surface of the muscle with the inferior gluteal artery was documented.

In order to determine whether a posterior approach to the hip could damage the inferior gluteal nerve, we made an incision across gluteus maximus from 5 cm distal to the posterior superior iliac spine to the tip of the greater trochanter of the femur.

Results
The specimens showed the close relationship of the deep surface of gluteus maximus to the inferior gluteal nerve (Figs 1 and 2). The nerve was always seen close to and medial to the sciatic nerve when it left the sacral plexus inferior to the piriformis. In all specimens, the nerve entered the deep surface of gluteus maximus approximately 5 cm from the tip of the greater trochanter of the femur and entered the deep surface of gluteus maximus over the inferior one-third of the muscle belly (Fig. 3).

When a muscle-splitting incision is made across gluteus maximus as part of the classical posterior approach\textsuperscript{11} and the muscle parted by hand-held or self-retaining retractors, the likelihood of damage to the inferior gluteal nerve is high (Fig. 4). The nerve enters the deep surface of the muscle and is not easily visualised and differentiated from other structures running with it, such as the blood vessels. Parting the muscle damages the nerve further by stretching or even rupturing its branches which run superiorly on its deep surface.

Discussion
The actions of gluteus maximus are to extend the trunk on the thigh, such as when raising the trunk from the stooped position, and to extend the hip when rising from sitting or during stair-climbing. External rotation of the femur at the hip is an additional action which occurs when the ipsilateral hemipelvis moves forward during gait. Failure to execute these actions may result in disturbances of gait, as observed by Perron et al.\textsuperscript{9}
The muscle originates from the outer surface of the ilium, the posterior surface of the sacrum and coccyx and from the sacrotuberous ligament. The muscle fibres pass downward and laterally and are inserted into the iliotibial tract and gluteal tuberosity of the femur. The muscle is supplied by the inferior gluteal nerve which arises from the dorsal branches of the ventral rami of the fifth lumbar and the first and second sacral nerves. It leaves the sacral plexus below the piriformis medial to the sciatic nerve and reaches the deep surface of gluteus maximus after a short distance. Tillmann observed in 17 of 112 subjects that the inferior gluteal nerve left the pelvis through the piriformis before entering gluteus maximus. The inferior gluteal nerve is accompanied by the inferior gluteal artery, a branch of the anterior trunk of the internal iliac artery.

Posterior approaches to the hip have been described by Osborne, and Moore. Gluteus maximus is split by an incision made along the line of its fibres and the edges are retracted. This allows rapid and easy exposure of the hip after detachment and retraction of the underlying external rotators. Displacement of and damage to the surrounding tissue are minimal, but if the fibres are split for more than 5 cm from the tip of the greater trochanter, damage to the inferior gluteal nerve may occur. In the approach described by Gibson, and Marcy and Fletcher all of gluteus maximus is left undisturbed and is retracted backwards while exposing the hip posteriorly with little risk to the nerve. However, it is cumbersome, requiring a long incision with wide mobilisation of the muscle. In addition, gluteus maximus and minimus have to be detached from the greater trochanter before the hip is reached. In the approach, described by Moore, the incision passes along the inferior border of gluteus maximus. Elevation of the muscle mass to reach the hip makes the exposure laborious. The direct muscle-splitting approach is therefore the preferred posterior access to the hip.

Our findings confirm the observations of Abitbol et al and offer a possible explanation for the persistently abnormal patterns of gait which are sometimes after THR, as described by Perron et al. We noted that the inferior gluteal nerve entered the deep surface of gluteus maximus very inferiorly. Hence, the incision in a classical posterior approach to the hip is highly likely to damage the branches given off to innervate the
superior portion of gluteus maximus. Weakness of hip extension may then occur.

In order to avoid injury to the nerve, we propose that a muscle-splitting incision of not more than 5 cm be made from the tip of the greater trochanter of the femur across gluteus maximus towards the posterior superior iliac spine. The lower part of the incision is extended distally for approximately 10 cm along the iliotibial tract (Fig. 5). This creates a modified posterior flap. The posterior gluteus maximus flap is raised and the underlying external rotators exposed. This route allows protection of the inferior gluteal nerve without having to go through a more extensive exposure to elevate the entire gluteus maximus.\textsuperscript{14,15} Posterior minimally-invasive approaches to the hip should take into account the point of entry of the nerve into gluteus maximus.

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