Over the past century, there has been a gradual evolution in socket design for transfemoral amputees from the plug fitting to pre quad, quadrilateral and then Ischial Containment (IC) designs. Many variations have been proposed within the IC philosophy such as: SABOLICH, UCLA, LONG, DOMINGUEZ HILLS and prefabricated brims such as IPOS, BREAKEY and other approaches.

The concept of anatomical socket shapes is not new. More than half a century ago, Thomas Canty from the U.S. Navy described his efforts to create an anatomical A/K socket. Most IC socket techniques do not incorporate the traditional Scarpa’s triangle contours although some create an acute angle at the anterior medial corner for relief of the Adductor Longus tendon.

Our introduction to Ischial Containment sockets occurred at UCLA in 1986 and, in the decades since then, we have modified our approach based on long term clinical experience with hundreds of transfemoral amputees. In 1999, one of our patients insisted upon an extremely low posterior trim line to improve the cosmesis of the buttocks. To our surprise, we discovered that since there was absolutely no gluteal support or containment in that socket, it was then much easier to fully contain the Ischial Tuberosity (IT) and part of the pubic Ramus. To provide better rotational control, the Scarpa’s region of the socket was modified to a shape similar to that in the classic quadrilateral shape, and the proximal anterior wall was lowered aggressively to permit a full range of active and passive hip motion.

This experience evolved into the Marlo Anatomical Socket (M.A.S. ®) design, which provides the transfemoral amputee with exceptional comfort and range of motion. M.A.S. ® sockets contain the Ischio-Pubic Ramus to provide coronal plane stability without any focused weight-bearing pressures. In addition to the unrestricted range of hip motion, patients who wear the M.A.S. ® report increased comfort, enhanced stability, and increased proprioception compared to other transfemoral sockets.

How does it work?

One primary difference between Ischial Containment and the M.A.S. ® design is that the IC socket fully encapsulates the Ischial Tuberosity (IT) and the ascending posterior Ischium. With the M.A.S. ® design, in contrast, the pelvic containment is as anterior as possible over the medial aspect of the Ischio-Pubic-Ramus. This results in excellent containment during mid-stance, which enhances coronal plane stability. The more posterior containment design of the IC socket means that the Ischium exits the socket much earlier single limb support, reducing coronal plane stability. The superior
stabilization of the M.A.S. ® design is confirmed by observing that the proximal lateral wall remains in contact with the skin on the flank throughout the entire gait cycle, without any visible gapping. It is important to note that the Ischial-Ramal-Containment (IRC) portion of the M.A.S. ® socket does not extend very far into the perineum: the height of the IRC “ear” is typically 2-3.5 cm proximal to the tip of the Ischium, while the width is not more than 5-6 cm. (Fig. 1)

![Ischio-Ramal Containment:](image)

Fig. 1

The 3 M.A.S. ® Principles

There are 3 fundamental principles that are essential to the creation of a successful M.A.S. ® socket. For a good final result, the prosthetist must focus on each principle in order.

1- **Tri-Planar Congruity** is the first principle, which means that the contours of the Ischial-Ramal-Complex must be accurately captured in the medial “ear” of the socket. This is accomplished when the IRC-to-Line-of-Progression angle, the inclination of the Ramus and the position of the inferior containment shelf are all accurately matched to the patient’s pelvic contours. (Fig. 2)

The basic concept of this design is to contain the Ramus without impinging upon it. It is imperative that the patient's IRC-to-LOP angle has been captured accurately in the cast and duplicated within the socket. Average angles vary between 25-30 degrees for males and 30-35 degrees for females, although there are some patients with more acute or more obtuse angles (Fig. 3). Patient comfort relies on the congruency between the Ramal angle and the medial containment wall. The inclination of the medial containment “ear” toward midline should be between 10-15 degrees to prevent any impingement of the IRC. The width of inferior containment shelf is typically 1 cm. but varies according to the tone of the adductor muscles. The medial socket wall provides a counterforce so that when the adductors fire, the socket is displaced slightly toward the midline. This reduces pressure on the IRC when muscles contract during mid-stance.
The clinical goal is to disseminate the overall socket forces so broadly that the patient cannot perceive any localized pressure on the IRC during static standing with double limb support. For a successful long term result, the IRC must be contained within the M.A.S.® socket in such a way that any pressure on the IRC is below the amputee’s perceptive threshold. If the amputee can identify concentrated pressures anywhere along the medial pelvis, the result is not a M.A.S.® socket.

2- **Balancing 3 Proximal Force Vectors** is the second principle, which is essential so that the IRC is “floating” within the containment “ear” without any weight bearing on the Ramus (Fig. 4).

The *A-P* force vector is the anatomical dimension from Ischial Tuberosity to the surface of the Adductor Longus tendon. The *skeletal M-L* force vector is measured from the medial aspect of the Ramus at the IT level to the sub-Trochanteric region of the femur. Both these measurements are routinely used in the design of Ischial Containment sockets. But having these two dimensions correct is not sufficient to stabilize the IRC within the containment “ear”.

The *Diagonal M-L* force vector is measured perpendicular to the IRC angle, from the medial aspect of the Ramus at the IT level to the Rectus Femoris muscle the antero-lateral aspect of the residual limb. It is only when the *A-P, M-L, and D-M-L* vectors are accurately “balanced” that the IRC will be “floating” within the medial “ear” during ambulation. Very small changes in any of these dimensions can have a pronounced effect on the position of the IRC within the containment region of the socket.

These 3 force vectors are key determinants of the anatomical shape of the socket, which must be congruent not only with the patient’s pelvic bones but also with the patient’s muscle contours.
One of the most critical aspects of the socket shape is the congruency between the posterior “U” shape of the socket that forms the Hamstrings channel and IRC angle. Moving laterally around the brim, the positive model should be modified so that the posterolateral sulcus has a flat or concave cross-section, to prevent loss of suction and help stabilize the femur. The area along the shaft of femur is flattened to help stabilize it in an adducted position. The Rectus Femoris muscle channel has a depth and half round contour that corresponds to the amputee’s muscle development. The Scarpa’s triangle region is broad and flat and may appear to be internally rotated compared to the Line-of-Progression. These contours also assist in rotational control of the socket. There is a pronounced relief for the Adductor Longus musculature and tendon in the medial corner of the socket, which can also accommodate excessive tissues due to volume fluctuation; this area does not have any biomechanical effect in the socket.

2. Accurate Counter-Pressures:
   3 Force Vectors
   "Ramal Containment NOT Weight Bearing"

Fig. 4

3- Only when we have the proper balance between the 3 force vectors do we apply mild tension values to create a quasi-hydrostatic weight bearing over the entire surface. (fig. 5) The flares should have nice radius around the perimeter of brim so the patient experiences no localized pressures.

3. Quasi-Hydrostatic Weight Bearing :
   "Gentle tension values + mild total contact"
Trim lines

The trim lines of a typical Ischial Containment socket are usually proximal to the Ischial level. The medial wall is generally lowered to avoid pressure on the Ramus and the posterior wall provides some measure of gluteal support.

In the M.A.S. ® design, the posterior and anterior walls are below Ischial level. In a typical case, the posterior trim line is 1.5 cm inferior to the IT for males and 3 cm inferior to the IT for females. The anterior trim line is 6mm higher than Ischial level near the Anterior Superior Iliac Spine (Fig 6). The anterior lateral contour is critical as the primary medio-lateral stability is derived from a snug fit from between the medial Ramus and the anterior lateral socket wall.

M.A.S. Trim Lines:

Fig. 5

Advantages

Amputees report that the radically different M.A.S. ® design for transfemoral sockets provides such benefits as:

- Increases sitting comfort
- Ease of donning (reduced restriction proximally)
- Unlimited hip joint Range of Motion - including external rotation of the hip
- Increased prosthetic control
- Enhanced stability
- Improved proprioception
- Better cosmesis

Range of motion
With the M.A.S. ® socket, there is almost no limitation in the range of motion of the hip, flexion (Fig. 7), extension, abduction, and adduction. This freedom allows the patient to increase their daily activities, such as using different exercise machines at the gym. The rotation of the hip joint is not limited by the socket and many patients can sit cross-legged without a rotator adaptor is not necessary to put it in top of the prosthetic knee (Fig. 8)

**Prosthetic control**

Amputees commonly report that the M.A.S. ® socket provides the best prosthetic control they have experiences. There is no Tredelenburg effect, the walking base is narrow, no rotational instability is apparent, and patients walk with equal stride lengths and demonstrate a relaxed, symmetric swing of both arms. These characteristics have been documented in numerous digital video clips.
Cosmesis

One additional benefit of the MAS® design is the exceptional cosmesis that results, with the trim lines being imperceptible under the patient’s clothing. The posterior wall usually terminates at the level of the gluteal fold. This improves cosmesis as the buttock is not elevated by the socket (Fig. 9). Amputees also comment on the added comfort because they sit on their gluteal muscle group, rather than on a hard socket brim.

For very short residual limbs, it may be necessary to keep the posterior trim line higher than normal to provide additional support.

Case illustrations

The author has fitted more than 250 M.A.S.® sockets to amputees with various levels of transfemoral amputations, different activity levels, using various suspensions including full suction with a valve, roll-on locking liners or a hypobaric membrane.

Case illustrations are offered to illustrate the advantages of this socket design. A residual limb with a very short femur, close to the gluteal fold level, was fitted with a suction socket and even with hip flexion of 140°, there is no loss of suspension. This gives the patient sufficient self confidence that she chooses not to wear an auxiliary suspension belt. (Fig. 10)

Bilateral amputees do well with the MAS® socket. Because these patients only walk for short periods of time, being able to sit on their own buttocks rather than on the socket brim is a considerable advantage over other designs. The range of hip flexion depends only on the patient’s flexibility and the length of residual limb.
The ability to cross one leg on top of the other, or to sit cross-legged, is another advantage of the MAS® design. This socket eliminates the need for a locking rotator proximal to the prosthetic knee (Fig.11).

In male patients, the narrow IRC-to-LOP angle makes the fittings particularly challenging.

This is not an easy socket to fit, requiring strict attention to detail and multiple test sockets for success. The best way to master the concept is to take a M.A.S.® seminar and then to fit several local patients, learning from this experience. It is rarely possible to learn the M.A.S.® method from reading the philosophy or from studying still photos or short video clips.

This socket design either fits perfectly or it does not; there is no “semi-M.A.S.®” socket. I have inspected many pseudo-M.A.S. sockets that do not fit or function properly, and naturally the patients complain and reject the socket. An experienced prosthetist usually requires 2-3 check sockets to get a properly fitting M.A.S.® socket for simple cases. More test sockets are required for complex cases.

Almost all transfemoral amputees can potentially benefit from the M.A.S.® socket design. The two exceptions are those patients who are so accustomed to their old socket shape that they do not want to change, or those patients who cannot provide accurate feedback. The intimately fitting M.A.S.® socket demands good communication between amputee and the prosthetist to achieve a good long term result. Significant volume fluctuations in the residual limb make it difficult to maintain a comfortable result.

Notwithstanding the additional time and effort required to create an intimately fitted M.A.S.® socket, the benefits that result in terms of comfort, cosmesis, and control significantly improve the quality of life for the transfemoral amputee.
Literature: