inForm BioDynamics
posture-specific saddle
design philosophy

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Executive summary

Bontrager inForm BioDynamic saddles are designed for the entire range of postures on a bicycle, from the most upright pelvic rotation to the most forward pelvic rotation. This document provides an in-depth explanation of how our saddles are designed the rider-saddle interaction, as defined by pelvic-rotation. The concepts outlined in this document apply to the male and female interaction with saddles.

The shape of Bontrager inForm BioDynamic saddles can be defined by three contours: curvature, profile, and transition. The curvature of the saddle is thought of as a cross-sectional view through the saddle at the critical point of the saddle where the rider is primarily seated. The profile contour is defined by the saddle’s shape in side view. The transition contour is defined by the edges of the saddle in the top view.

Bontrager inForm BioDynamic saddles are categorized by five postures: leisure, fitness, performance, aggressive, and aerodynamic. Each inForm BioDynamic saddle combines the ideal curvature, profile, and transition to best suit the posture of its intended rider.
White paper philosophy

Bicycle saddles provide the most intimate connection between cyclist and bicycle. The most minute details of a saddle can make it a supportive cloud for one rider, a torture device for another. For years those details were considered more art than science, and the process of designing (or selecting) the right saddle could take years of trial and error. Now, Bontrager has changed the game with inForm BioDynamics.

This paper will explore how Bontrager has used pressure mapping and Finite Element Analysis (FEA) to develop industry-leading understanding of every detail of the rider-saddle interaction, so we can design the ideal saddle for every cyclist and every riding style. By explaining how we design saddles, we provide a better understanding of what saddle will work best for you.

Introduction

This paper is divided into six sections:

Section 1 provides a background on the bony anatomy of the pelvis. These anatomical terms are referenced throughout the document.

Section 2 describes the design tools used to develop Bontrager inForm BioDynamic saddles.

Section 3 describes the rider-saddle interaction within each posture.

Section 4 outlines the three contours that can be used to describe the shape of any saddle in three orthographic planes. These contours are curvature, profile, and transition.

Section 5 describes the materials used in saddle construction.

Section 6 provides the 2014 Bontrager saddle line as they relate to each posture category.
1 Pelvic anatomy

1.1 Ischial tuberosities (ITs/"sit bones")
The ITs are the bony landmarks at the lowermost point of the pelvis (Figure 1).

1.2 Pubic rami
The pubic rami are the bony structures extending from the ITs toward the cartilaginous joint known as the pubic symphysis (Figure 1).

1.3 Pubic arch
The pubic arch refers to the upper portions of the pubic rami, underneath the pubic symphysis (Figure 1).

Key
1. ischial Tuberosities
2. pubic Rami
3. pubic Arch
4. pubic symphysis

Figure 1 Pelvic anatomy
2

Design tools
The philosophy behind inForm BioDynamic saddles is the result of countless elite athlete ride tests, pressure mapping sessions, high-speed video analyses, and human computer modeling studies. These tools, used by a team of mechanical and biomechanical engineers in conjunction with Trek Precision Fit, help refine the minute details that go into the complete Bontrager line of posture-specific saddles.

2.1 Athlete ride testing
Targeted elite athlete ride testing (Figure 2) provides us with invaluable feedback during a saddle’s design phase. We target specific athletes for each inForm saddle, based on their desired pelvic rotation on the bicycle. This ensures proper feedback that is critical to the shape and material selection for each individual saddle. This qualitative feedback is then correlated to the data collected using the instruments outlined as follows.

Figure 2 Elite athlete rider testing
2.2 Pressure mapping

We worked directly with global pressure mapping experts novel GmbH, who developed a custom capacitative pressure mapping solution for us with an extremely high sensor resolution. The mat itself is elastic to contour to the saddle, and it can be calibrated on site to ensure both precision and accuracy. This equipment allows us to gather quantitative data about the rider-saddle interaction (Figure 3). We use the data collected to verify that the rider’s pressure is distributed properly on the saddle, with weight bearing on the bone structure and pressure relieved on the soft tissues. The high sensor resolution helps identify if any areas on the saddle cause “hot spots” of high pressure that lower-resolution systems struggle with. This equipment allows us to run controlled studies in the lab, and also more true-to-life studies out on the road while recording to a memory card. Video data collected with the pressure mapping equipment is perfectly in sync, allowing a dynamic analysis of the pressure distribution on the saddle as a function of the pedal stroke.
2.3 High-speed video

High-speed video analysis (Figure 4) is used to ensure the rider is properly supported by the saddle throughout the pedal stroke. The motion of the rider, the saddle, and the seat post are isolated to gain understanding of the relative motion between the three objects. Using high-speed video analysis, we can analyze the saddle shape and structure to ensure that the rider is well supported, and that the saddle facilitates a proper pedal stroke.

Figure 4 High-speed video analysis of the 2014 Nebula+ saddle
2.4 Human computer modeling

Bontrager collaborates directly with researchers from the Frankfurt University of Applied Sciences to develop cutting-edge computer models of the rider-saddle interaction. We use these human computer modeling studies (Figure 5) to gather a further understanding of the internal stresses and strains on skin tissue, adipose tissue, muscle tissue, bone tissue, nerves, and arteries when a rider interacts with the saddle\(^1\). The studies use Finite Element Analysis (FEA) to analyze the compression of these tissues under load from the saddle. This helps us identify the effect of shape and material properties on the stresses and strains of the rider’s soft and hard tissues. Through this innovative research, Bontrager has developed an incredibly thorough understanding of the rider-saddle interaction. This allows us to provide our riders with best in class products that excel beyond the competition.

![Figure 5 Human computer modeling](image_url)
3

inForm BioDynamic postures

The posture of the rider determines which portion of the pelvis is in contact with the saddle, which makes it the main determinant of the saddle’s form. The shape of the saddle must properly support the skeletal structure while relieving pressure on the soft tissues of the rider in that posture.

The chart below shows the five inForm BioDynamic categories of posture, ranging from the most upright pelvic rotation of posture 5, to the most forward pelvic rotation of posture 1.

As riders reach for a lower handlebar position, they may round their backs, rotate their pelvises, or both. The posture categories defined in this document refer to the rotation of the pelvis, as pelvic rotation determines the pressure distribution on the saddle. Riders that primarily round their backs to reach for the handlebars may opt for a saddle that is designed a relatively upright posture.
3.1 Pressure vs. posture

As seen in Figures 8–12 below, saddles are designed for a range of five postures. As riders rotate their pelvises forward, weight distribution on the saddle moves from the ischial tuberosities to the pubic rami (Figure 7). The pubic rami are therefore the primary support structure for riders of the Fitness, Performance, and Aggressive Postures.

3.1.1 Posture 5: leisure

Riders with a leisure posture have the least amount of pelvic rotation, and are supported by the ischial tuberosities, or “sit bones”, of the pelvis.
3.1.2 Posture 4: fitness
Riders with a fitness posture are supported by the pubic rami of the pelvis near the ischial tuberosities.

3.1.3 Posture 3: performance
Riders with a performance posture are supported primarily by the pubic rami.
3.1.4 Posture 2: aggressive
Riders with an aggressive posture are supported by the pubic rami near the pubic arch.

![Figure 11 Aggressive posture](image)

3.1.5 Posture 1: aerodynamic
Riders with an aerodynamic posture have the most forward pelvic rotation, and are therefore largely supported by the pubic arch of the pelvis.

![Figure 12 Aerodynamic posture](image)
4

Saddle design features

Our design philosophy uses Bontrager-developed terminology to describe the three critical contours of the saddle: curvature, profile, and transition. These three contours are determined during the design phase of a saddle when the intended posture of the rider is identified. Each saddle is designed for one of the intended postures. The charts in Section 4 show the relationship between the three critical contours of the saddle and the posture category.

4.1 Curvature

Curvature defines cross-sectional shape (Figure 13) of the saddle and affects the angle at which forces are transmitted from the saddle to the rider’s bone structure. Bontrager inForm BioDynamic saddles are developed with Size Specific Curvature. This means that the saddles are designed with three sizes in order to properly support the full range of pelvis widths. Section 4.1.1, curvature vs. posture, applies to all pelvis widths.

4.1.1 Curvature vs. posture

The critical cross-section of curvature on the saddle is directly underneath the bone structure of the rider. This critical cross-section is therefore further back on saddles for upright postures and further forward on saddles for more aggressive postures (Figure 14). The curvature should be flat, concave, or removed (a cutout), between the hard tissues (bone) of the rider. A convex shape in this area of the saddle causes an increase in perineal pressure for both men and women.

<table>
<thead>
<tr>
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Figure 13 Curvature

Figure 14 Saddle curvature in primary seated area
4.1.2 Curvature with cutouts/reliefs

Cutouts in saddles may exist in the foam, the shell, or both. Cutouts are designed to relieve pressure on the soft tissues, while not creating hotspots of pressure on the soft and/or hard tissues.

Contour Relief Zones (CRZ), or foam depressions, can often serve the purpose of a cutout, while still providing support directly under the relief. This may sometimes be preferable for riders who find the small surface area provided by a traditional cutout saddle to be painful (less surface area=higher pressures).

Cutouts (CRZ+) become more significant for saddles designed for aggressive postures (Figure 15). This is not to say that all aggressive posture saddles need cutouts, but the cutout design itself becomes very important for these saddles because there is direct pressure on the perineum when the pelvis rotates forward on the saddle. Because of the way the pudendal nerve and artery run along the pubic rami for men and women, for some cyclists, full cutouts may place excessive pressure on this nerve and artery. For other cyclists, the cutout will allow for proper distribution of pressure to the bone, while avoiding the pudendal nerve and artery.

Figure 15 2014 Paradigm R saddle with CRZ+
4.2 Profile

Profile defines the side-view shape (Figure 16) of the saddle and affects how much the rider is able to move fore/aft on the saddle. The profile may also affect the rider’s pelvic rotation on the saddle.

4.2.1 Profile vs. posture

The profile of the saddle affects where the rider settles down on the saddle (this is also true for the transition of the saddle, as discussed in section 4.3). The more pronounced the profile, the more it affects the rider’s fore-aft position on the saddle. The profile should be mostly flat for upright riders, and more pronounced for more aggressive riders, as seen in Figure 17 below. A flatter profile allows the upright rider to sit further back on the saddle, getting more surface area underneath his or her skeletal structure. This also allows the rider to move fore/aft on the saddle easily for different grip positions/riding conditions, without changing pelvic rotation (i.e. staying upright).

More pronounced profiles assist riders into a forward rotated position of the pelvis, and are therefore desirable for more aggressive postures. These saddles traditionally have a “sweet spot,” and riders can rotate their pelvis in one place on the saddle for different grip positions/riding conditions, rather than move fore/aft on the saddle. Notice in Figure 17 that saddles of all posture categories should be set up horizontal in the primary seated area. Some riders may adjust the angle of the saddle by 1–2 degrees to find their appropriate tilt. A saddle that is tilted downward will often result in hand, neck, and upper back pain, as well as increased perineal pressure since the pelvis continually slides forward on the saddle. By returning the saddle to horizontal in the primary seated area, the pelvis becomes properly upported, reducing pressure on the hands and perineum.
4.3 Transition

Transition defines the top-view shape (Figure 18) of the saddle and primarily affects the fore/aft position of the rider on the saddle surface.

![Figure 18 Transition](image)

4.3.1 Transition vs. posture

The transition of the saddle (Figure 19) affects where the rider settles down on the saddle (this is also true for the profile of the saddle, as discussed in section 4.2). More pronounced transitions work best for upright riders because the saddle remains out of the way of the leg as it moves through the motion of turning the crank over. More gradual transitions work best for aggressive riders because gradual transitions allow riders to be supported by a structure that is parallel to their pubic rami. For men, this transition is more gradual for aggressive riders than for women. This is because the pubic arch is narrow and triangular in shape for the average male pelvis and wide and shallow for the average female pelvis. Gradual transitions also allow riders of varying pelvis sizes to find comfortable homes on the same saddle, with narrower pelvises settling slightly further forward than wider pelvises.

![Figure 19 Saddle transition](image)
4.4 Aerodynamic saddles

Triathlon and time trial saddles are designed for a unique rider-saddle interaction. Often tri/TT riders interact with the nose of the saddle with an extremely forward rotated pelvic position. These riders therefore benefit from a saddle that has a nose with a flat profile, creating a platform where they can rest stably. Some riders will trend towards saddles without a cutout in order to increase the overall area of the saddle to distribute pressure (Figure 20). Other riders will prefer a split-nose design, where the cutout of the saddle runs entirely through the nose of the saddle, providing perineal relief (Figure 21).

Most Tri/TT riders will have to experiment with both saddle styles in order to figure out which style is best for their anatomy. After first racing the split-nose Hilo saddle in the 2012 Paris-Nice race, Andy Schleck stated, “For me it was something extraordinary because I could ride my bike without pain and stay in the same position for a long time.” Half the pro tour team, along with Andy, continues to ride the Hilo saddle on their TT bikes.

Figure 20 2013 Team Issue TT saddle

Figure 21 2014 Hilo XXX Tri/TT saddle
5

Construction materials

The previous descriptions outline saddles in their simplest form, a basic 3-D footprint in space. However, there is more to a saddle than just shape.

5.1 Materials

The materials used for the rails, shell, foam, and cover have a direct effect on saddle comfort.

The rails of the saddle provide a mechanism to clamp the saddle to the seat post. The Bontrager Serano, for example, uses a proprietary rail design that allows for ample shell compliance in the aggressive riding posture (Figure 22).

The overall stiffness of the shell is accomplished through direct supports, called ribs, or through reinforcing fibers such as carbon or glass when the shell is constructed of nylon. The shell of the saddle provides the primary support for the rider. The form of the shell is therefore designed to distribute pressure to rider’s bone structure and provide relief to the rider’s soft tissues.

The foam of the saddle provides the primary shock absorption and vibration damping properties of the saddle. Like the shell, the shape of the foam is designed to distribute pressure to the rider’s bone structure.

The Bontrager Hilo Tri/TT saddle (Figure 23) uses a proprietary Smart Cover design that stiffens the rear of the saddle for upright efforts and softens the nose of the saddle for a forward-rotated, aerodynamic posture on the bike. The cover is also designed to reduce friction. Increased friction lowers the perfusion of blood from arteries to the surrounding tissues, and may lead to saddle sores. Friction is mitigated by proper bicycle shorts, but the cover material plays an integral role.

Figure 22 2014 Serano RXL carbon rails

Figure 23 2014 Hilo XXX Smart Cover
Some saddles use gel in order to provide cushion and further reduce vibration. A layer of gel between the shell and the foam can help prevent the "bottoming out" feeling sometimes experienced by riders when they fully compress the foam into the shell (Figure 24).

**5.2 Elastomers**

Some saddles use elastomers to separate the direct connection between the saddle rails and the shell. Elastomers may exist in the rear or nose garages of a saddle. Elastomers in the rear rail garages (Figure 25) are more beneficial for upright riders, while elastomers in the nose garages are more beneficial for aggressive riders.
2014 Bontrager saddle line

The following table summarizes the 2014 Bontrager saddle line, which reflects the design philosophy described in this white paper.

Note that the Paradigm series of saddles is relevant for both posture 2 and posture 3. This is because the Paradigm was designed not only to support the rider on the pubic rami, but also to allow the rider to rotate toward the pubic arch thanks to the CRZ+. Riders on the performance end of the spectrum may trend toward the Paradigm R due to the increased foam under the pubic rami. Riders on the aggressive end of the spectrum, who are supported by the pubic rami near the pubic arch, may benefit from the flex properties of the Paradigm XXX.

<table>
<thead>
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<tr>
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<td>Nebula</td>
<td>Paradigm Series</td>
<td>Hilo Series</td>
<td></td>
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<tr>
<td>Boulevard</td>
<td>SSR</td>
<td>Affinity Series</td>
<td>Serano Series</td>
<td>Team Issue TT</td>
</tr>
<tr>
<td>Cruiser</td>
<td>Commuter Gel</td>
<td>Evoke Series</td>
<td>Team Issue</td>
<td></td>
</tr>
<tr>
<td>Sport</td>
<td>Rhythm</td>
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Figure 26 2014 saddle line breakdown by posture
Glossary

**adipose tissue**  
fat-storing body tissue

**hard tissues**  
bone structure

**ischial tuberosities**  
the lowermost bony landmarks of the pelvis, also known as sit bones.

**pubic arch**  
the bony structure of the pelvis where the pubic rami meet

**pubic rami**  
the portion of the pelvis that extends from the ischial tuberosities toward the pubic arch

**pudendal artery**  
blood supply to external genitalia of both sexes

**pudendal nerve**  
innervates the external genitalia of both sexes

**sit bones**  
also known as ischial tuberosities

**soft tissues**  
the muscles, fascia (fat), tendons, ligaments, nerves, arteries, and veins that surround the bone structure

References