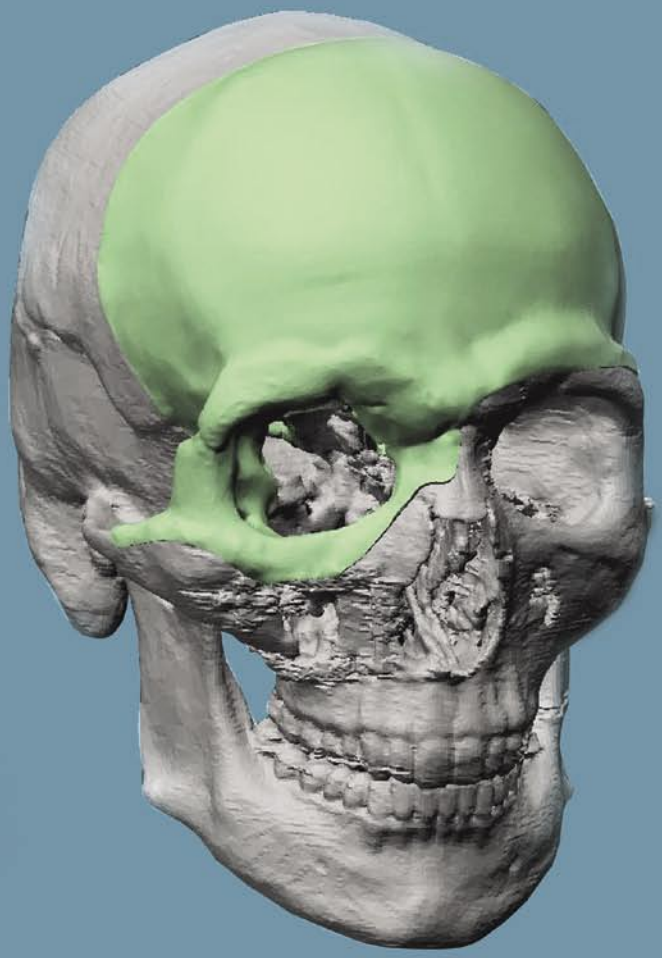
完美替换缺失部分颅骨的修补物与患者颅骨的复合图像
A combined image showing a patient's skull with the prosthesis designed to replace a missing piece of skull fitting perfectly



虚拟成像与实体模型

成功分离大脑连体儿，正是得益于三维模拟

Virtual images and physical models

Seperating cerebrally conjoined twins was just one successful operation that has greatly benefited from three-dimensional modelling

分离连体双胞胎有时候只是一项直接了当的手术而已；然而，在其它情况下却不可能进行。2003年，美国巴尔的摩约翰霍普金斯大学接手一个来自德国的案例，这是一个可想象到的最为复杂的案例之一：两个女婴头部发生联体，皮肤与骨骼都没有将二人的大脑分离开来。

Ben Carson博士是一个专攻连体婴儿案例的神经外科医生，以其为首的50多名专家组成的手术小组是世界上最好的手术队伍之一。他们最需要观察到患者颅内的真实状况。

医学成像具有着100多年的历史，这一领域取得了惊人的进展。在现行标准实践中，大多数成像技术的问题是这些技术提供的是二维视图。核磁共振成像（MRI）、计算断层分析（CT）扫描与陈旧的备用设备——X光，都是对患者身体生成二维片段。

每种技术都受到可收集信息的制约。X光与CT扫描具有对骨骼组织及其它硬组织成像的最佳性能，而核磁共振成像对器官与肿瘤等软组织能够进行更好的成像。医生和外科医生可以从这些图像中获得许多信息，而且，医学扫描分辨率也得到了提高，可以对圆周内1毫米长的目标进行成像。

医生不得不通过二维图像来表现出三维图像。获得准确的容积方法具有一定困难，在这种复杂情况下，医生们有时候会很难了解软组织与周围骨头之间的精确关系、神经与血管的准确位置以及婴儿脑部表面结构。

Able Software公司的3D-Doctor等先进三维医学成像系统能够将通过不同技术拍摄到的多个片段进行合并，构造出手或整个头部等人体复杂部位的高清晰度、彩色三维医学图像，显示骨与软组织之间的精确关系。

“现在，三维医学成像技术已经相当成熟，”Able Software公司创始人及首席执行官、3D-Doctor设计师Ted Wu说，“三维体积彩视法可以从用于外科手术平面图、模拟、治疗计划、肿瘤容积计算及其它定量分析中的CT和核磁共振成像扫描中产生。”

所有这些性质都已证明对连体双胞胎病例及其它复杂的医疗过程具有重要意义。而三维医学成像系统通常力图获取某一结构外表面的精确模型；在这一病例中，这个结构便是连体双胞胎的头部，并且它们不会生成能够让外科医生巧妙操作的实体模型。

这对于约翰霍普金斯医院整形与重建外科事业部唇裂与上颚门诊联席主任Richard Redett而言，曾经是一项挑战。他是这一队伍的主整形医师，负责在手术后将婴儿头部缺口进行缝合，保护婴儿大脑，不至于使其暴露在空气中。

在手术早期，他在婴儿的颅骨皮下插入了组织扩张器，这些组

Separating conjoined twins can be a straightforward operation in some cases; in others it can be impossible. The case that arrived from Germany on the doorstep of Johns Hopkins University in Baltimore, US in 2003 was one of the most complicated imaginable. Two baby girls were conjoined at the head with neither skin nor bone separating their brains.

The surgical team, numbering around 50 experts led by Dr Ben Carson, a neurosurgeon specialising in conjoined twin cases, was one of the best in the world. But what they really needed was to literally see inside their patients' heads.

Medical imaging is more than a century old and advances in the field have been spectacular. The problem with most imaging techniques in current standard practice is that they only give two-dimensional views. Magnetic resonance imaging (MRI), computed tomography (CT) scans and X-rays all produce two-dimensional slices of a patient's body.

Each technology is limited in what information it can capture. X-rays and CT scans provide the best images of bones and other hard tissues, while MRIs are much better for providing images of soft tissues such as organs and tumors. Doctors and surgeons can gain a great deal of information from these images, and the resolution of medical scanning has improved to the point that objects one millimeter in circumference can be imaged.

But with two-dimensional images doctors have to interpret what the three-dimensional object looks like. Getting precise volume measurements is difficult, and in cases this complex it is difficult to understand the precise relationship of the soft tissue to the surrounding bone, the precise location of nerve and blood vessels, and the surface structures of the babies' brains.

Advanced three-dimensional medical imaging systems like 3D-Doctor from Able Software can combine multiple slices taken by different imaging technologies to construct highly accurate, multicolour three-dimensional medical images of complex parts of the human body such as hands or complete heads, showing the precise relationship between bone and soft tissue.

"Today, three-dimensional medical imaging technology is quite mature," says Ted Wu, founder and CEO of Able Software

织扩张器实际上就是能够逐渐充满盐溶液的气球，目的是为了使皮肤足够伸展，能够在术后将开口覆盖。但是他却发现自己无法保证得到足够的皮肤。同时，他只有一次机会获得真皮并将其拼凑起来，他确实需要一个实体模型来练习。该医院得到了美国马里兰州欧文斯米尔市Direct Dimensions公司的帮助，该公司的主要业务是提供先进的三维测定、数字化及逆向工程服务。

该公司与约翰霍普金斯大学在手术之前建立了关系。它已经帮助约翰霍普金斯大学应用医学技术系认证整形师、该医院面部修复门诊部主任——Juan Garcia进行了各种修复项目。

外科医生只有一次机会获得真皮并将其拼凑起来，他确实需要一个实体模型来进行练习

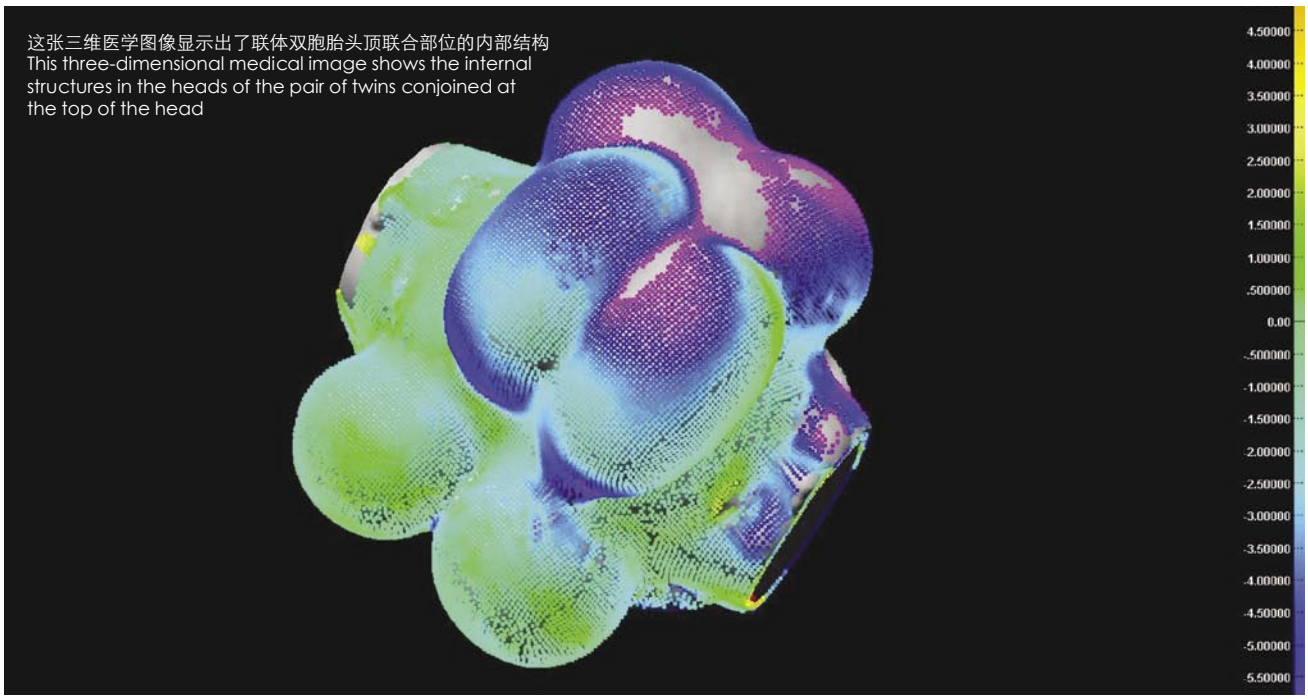
“这是一个具有代表性的问题，”Direct Dimensions公司首席执行官Michael Raphael说，“需要为修复手术创造出一个原本就不存在的左耳。”这通常是通过制造一个右耳的石膏模型来完成。但是，铸件无法轻易地从左侧翻转到右侧。因此，整形师不得不手工雕刻出左耳，这是一项艰难而又耗时的工序。另外，如果最后的硅酮修复术是借助骨整合植入的话，外科医生必须对患者头部左侧进行探究性手术，进而确定植入的最佳位点，而这毫无疑问地会穿透颅骨。

and designer of 3D-Doctor. “3D volume rendering can be performed on a personal computer in real time. 3D models can be created from CT and MRI scans for surgical planning, simulation, treatment planning, tumour volume calculations and other quantitative analysis.”

All of these qualities have proved important in the conjoined twins case and many other complex medical procedures. But where three-dimensional medical imaging systems usually struggle is getting a precise model of the outside surface of a structure; in this case, the twins' heads. And they do not create physical models that surgeons can manipulate.

This was the challenge that Richard Redett, co-director of the Cleft Lip and Palate Clinic in the Division of Plastic and Reconstructive Surgery at Johns Hopkins Hospital, faced. As the chief plastic surgeon on the team, he was responsible for sealing the gap at the tops of the babies' heads once they were separated to protect their brains, which otherwise would be exposed to the air.

Early in the process he had inserted tissue expanders, essentially balloons that could be slowly filled with saline solution, under the skin on the twins' skulls to stretch the skin to create enough to cover the openings. But, he realised, he had no assurance that he had enough skin. Also, he would only get one chance to cut the real skin and piece it together, and he really needed a physical model on which to practice. The hospital elicited the help of Direct Dimensions of Owings Mills, US, whose main business is providing advanced three-dimensional



这张三维医学图像显示出了联体双胞胎头顶联合部位的内部结构
This three-dimensional medical image shows the internal structures in the heads of the pair of twins conjoined at the top of the head

取而代之，Direct Dimensions公司可以利用一台专门为工业应用而制造的扫描设备，对患者头部进行准确的表面激光扫描，在扫描时，该设备对病人的眼睑不造成伤害，随后，成像软件可将天生耳进行翻转。这样，Garcia可为人造耳寻找最佳位点，将植入物钻入颅骨。点击一个按钮，随后将虚拟的三维图像发送给一个工业模型制造器，它用树脂创造出一个耳朵的快速原型模型和手术钻模板，供整形师与外科医生使用。这能够让整形师创造出一个能够与天生耳最佳匹配的人造耳，同时让外科医生将人造植入物安置在最佳的地方。

通过这项修复术的初步进展，Direct Dimensions公司与多家华盛顿区域的先进医疗机构建立关系，而承接更为复杂的病例又不可避免。瓦尔特·里德陆军医疗中心与Raphael联系，希望其公司帮助设计出一种能够替换受伤士兵颅骨缺失部分的修复术。

“士兵的健康虽有好转，只可惜失去了大片颅骨，”Raphael说道。该医院通过3D-Doctor快速模拟出士兵的颅骨与周围的软组织，随后将颅骨的CT扫描发送给Direct Dimensions公司。为失去的骨头设计出精确的修补物，是一项挑战。

“我们实际上做的是：从另一个投影中处理出一张颅骨图像，使其与士兵的颅骨大小一样，之后将它们相互重叠，”Raphael说，“然后，我们将与士兵重叠第二块颅骨完全去除，剩下的部分便是我们的修补物模型的基础。”

一旦完成这些操作后，Direct Dimensions公司便可以快速并极为精确地创造出最终植入物的钻孔图与树脂模型，为患者的手术过程与痊愈作出了巨大贡献。

因此，Garcia在对连体双胞胎进行手术之前求助Direct Dimensions公司就不难想象了。通过连体双胞胎头部表面激光扫描与配套CT医学图像，成像专家们能够生产出皮肤扩张器膨胀前后婴

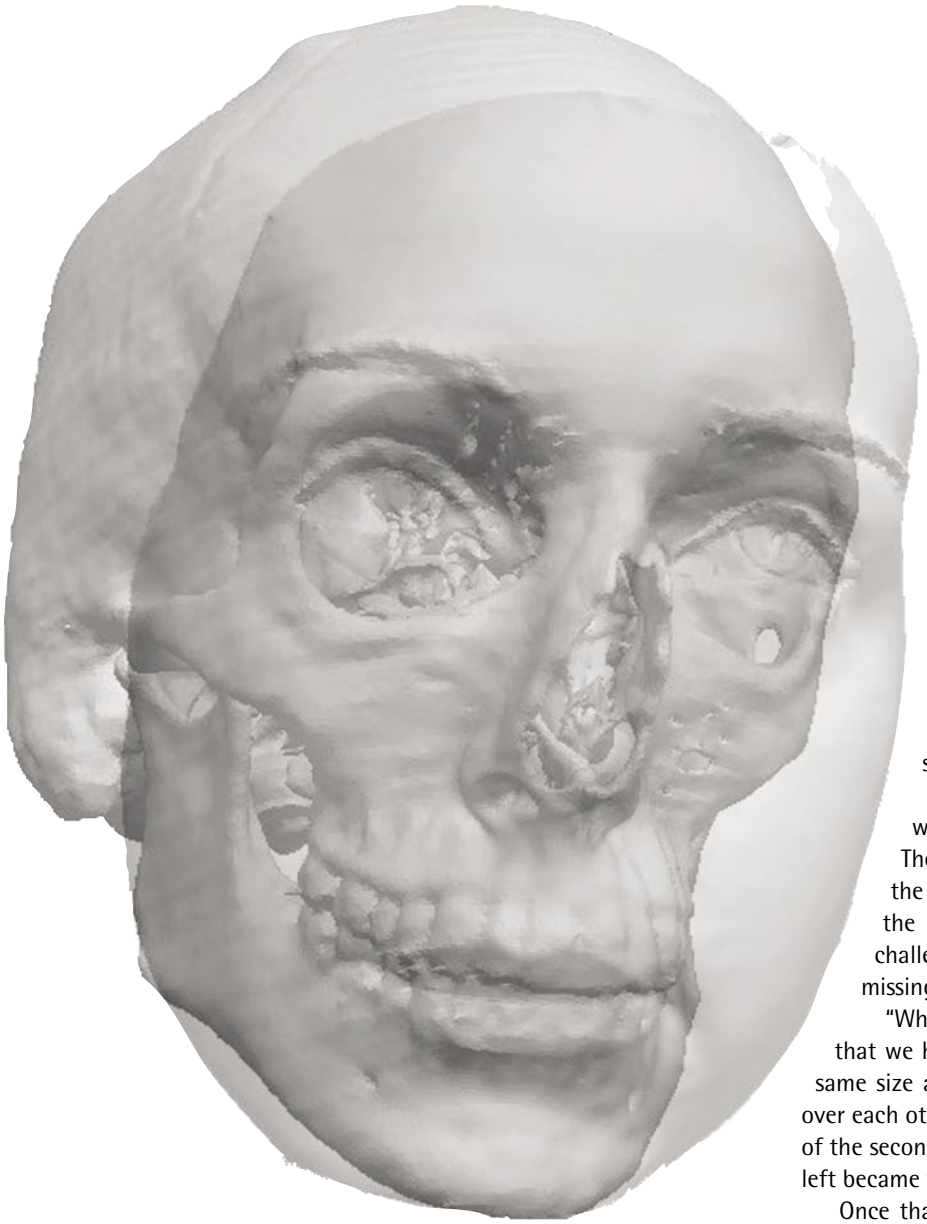
measurement, digitising and reverse engineering services.

The company established a relationship with the John Hopkins University before the operation. It has helped Juan Garcia, a certified anaplastologist in the Univeristy's Department of Art as Applied to Medicine, in various prosthesis projects he works on as the Director of the Facial Prosthetics Clinic in the hospital.

"A typical problem," says Michael Raphael, chief executive of Direct Dimensions, "is the creation of a prosthesis for a missing left ear". This is normally achieved by making a plaster cast of the right ear. However, a cast cannot be readily flipped from left to right. So the anaplastologist has to sculpt a model of the left ear by hand, a difficult, time-consuming process. And if the final silicone prosthesis is to be held on via osseointegrated implants, surgeons essentially have to do an exploratory surgery of the left side of the patient's head to determine the best sites for the implants that have to be drilled into the skull.

Instead, Direct Dimensions can make a precise, surface laser scan of the patient's head using a scanner built for industrial applications that is safe for scanning over patient's eyelids, and then use imaging software flip the unaffected ear. This allows Garcia to locate the best spots relative to the prosthetic ear to drill implants into the skull. A click of a button then sends the virtual three-dimensional image to an industrial model maker that creates a rapid prototype model of the ear and surgical drilling template from resin for the anaplastologist and surgeon to use. This allows the anaplastologist to create a prosthesis that better matches the unaffected side and the surgeon to better place the

整形师Juan Garcia将此连体双胞胎头部模型用聚亚安酯覆盖，模拟成皮肤的样子，供手术队伍练习覆盖双胞胎头顶缺口的整形手术
Anaplastologist Juan Garcia covered this model of the twins' heads with polyurethane to create several skins that the surgical team could use to practice the plastic surgery needed to cover holes that would be left at the top of the twins' heads



患者面部的表面扫描及表面下颅骨的三维医学图像，通过3D-DcotorCT扫描产生。复合图像对脸部重建手术非常有用
A surface scan of a person's face combined with a three-dimensional medical image of the skull beneath, generated from CT scans using 3D-Doctor. Combined images are very useful in facial reconstruction surgery

implants relative to the prosthesis.

From this initial outing in prosthesis, Direct Dimensions came to establish relationships with several leading medical institutions in the Washington DC area and inevitably to more complex cases. The Walter Reed Army Medical Center contacted Raphael to help design a prosthesis to replace a missing piece of an injured soldier's skull.

"The soldier was doing well, except that he was missing a large piece of skull," says Raphael. The hospital sent Direct Dimensions its CT scans of the skull, from which 3D-Doctor quickly modelled the soldier's skull and surrounding soft tissues. The challenge was to design a precise prosthesis for the missing bone.

"What we actually did was manipulate one skull image that we had from another project to make it precisely the same size as the soldier's skull and then superimpose them over each other," Raphael says. "We then removed all the parts of the second skull that overlapped the soldier's and what was left became the basis of our model of the prosthesis."

Once that was completed, Direct Dimensions was able to create the drilling map and resin model for the final implant quickly and with great accuracy, contributing materially to the success of the procedure and recovery of the patient.

It was natural, therefore, for Garcia to return to Direct Dimensions to help operate on the conjoined twins. Armed with a surface laser scan of the twins' heads and a full set of CT medical images, the imaging specialists were able to create milled models of the babies' heads both before and after the skin expanders were inflated. From these models Garcia was able to create several polyurethane "skins" with the elasticity of real skin. Redett and his team of plastic surgeons used these to determine first that they had enough skin to cover the affected area, and then to physically practice cutting and placing the skin over the tops of the twins' heads once they were separated. This gave them the confidence that they could do reconstruct the patients' heads in the best possible way.

The full surgical team used the model of the twins' head in a rehearsal of the actual procedure. With approximately 50 members involved in an operation that would stretch over two days, it was vital for everyone to understand where they

"当外科医生遇到了一些自己不是很清楚的事情时，他们可以进入到另一个房间，戴上虚拟实景目镜观察各个水平、直至脑部的颅骨与血管"

—Redett，约翰霍普金斯医院

儿头部的轧制模型。通过这些模型，Garcia能够制造出很多个聚亚安酯“皮肤”，它们有着与真皮一样的弹性。Redett及其整形外科医师团队使用这些技术，首先确定他们是否具有足够的皮肤来覆盖手术区域，然后进行切割以及在联体双胞胎被分离后，在它们的头顶覆盖上皮肤的实体练习。这使他们对有能力采用最好的可能方法来重建患者头部充满了信心。

整个手术小组在实际过程中，使用了联体双胞胎的头部模型进行了演习。有大约50人参与了手术，手术持续时间超过两天，通过这一过程使大家明白自己应该在哪里进行手术，这一点至关重要。

同时，独立的虚拟三维计算机模型证明了其本身是一个有价值的外科手术工具。“在这个过程中，双胞胎的虚拟模型是在手术台旁边的房子中进行试验的，”Redett说，“当外科医生遇到了一些自己不是很清楚的事情时，他们可以进入到另一个房间，戴上虚拟实景目镜观察各个水平、直至脑部的颅骨与血管。这对于神经外科具有重要意义，使这类手术的方法产生变革。”

于是，分离手术变得更加顺利，闭合伤口的整形手术也很成功。不幸的是，双胞胎之一由于心脏问题死亡，而这跟手术没有关系。而另一个孩子正在德国过着正常人的生活。

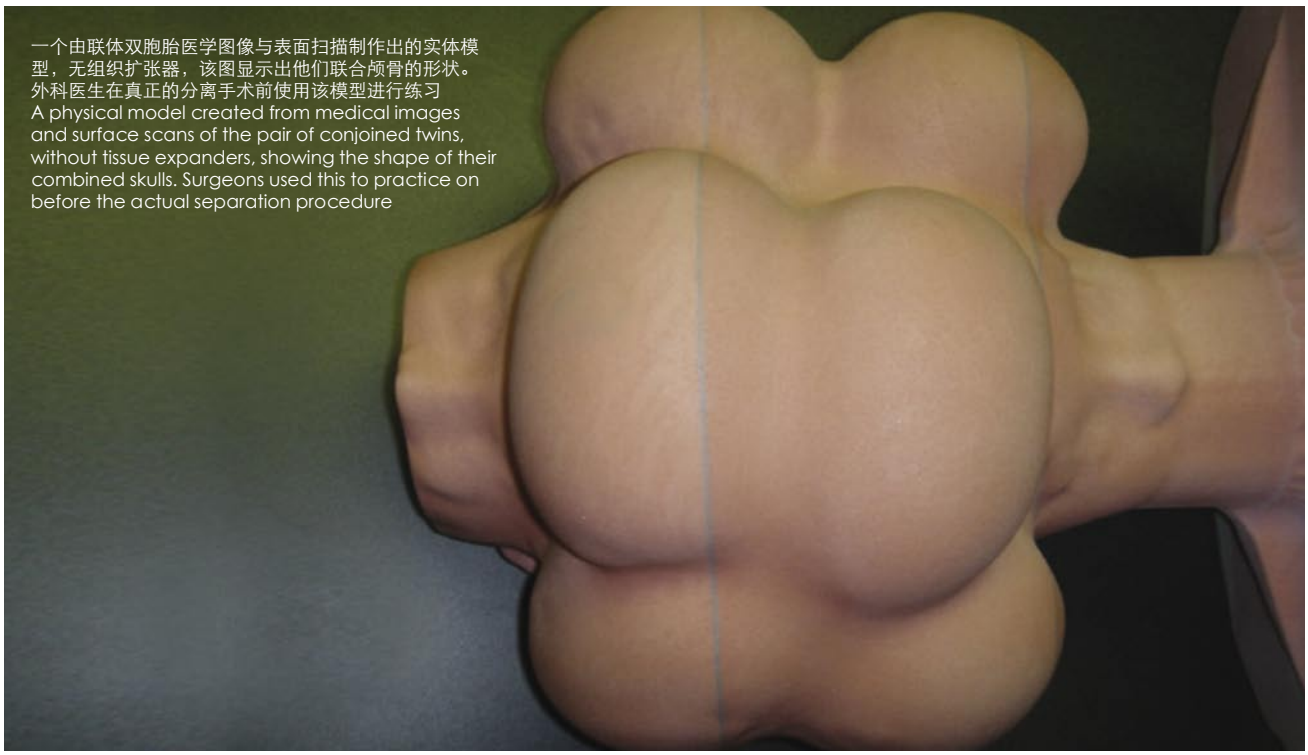
总的说来，Redett认为三维成像能力对于复杂病例取得成功极为重要。“我认为这一领域具有开放性，”他说，“我已经多次使用了这一技术，用于给车祸、枪伤或癌症造成后颅骨缺失的儿童或成年人重建颅骨。当我得到一张三维CT扫描图像后，我将它送到Direct Dimensions公司制作模型；他们是拿钛或聚合物制成模型，然后，我可以将这个完美定制的模型植入进病人的颅骨。”随着该技术的发展，在将来，它会被用在越来越多的医学应用当中。

needed to be through the process.

A separate virtual three-dimensional computer model proved itself a valuable surgical tool as well. “During the procedure, the virtual model of the twins was running in the room next to the operating theater,” Redett says. “When the surgeons ran into something they were not completely sure they understood, they would go into the other room, put on the virtual reality goggles and see the skull at any level down to the brain and blood vessels. That was very important for the neurosurgeons. It revolutionises the way this kind of surgery can be done.”

As a result the separation went more smoothly and the plastic surgery to close the wounds was successful. Unfortunately one of the twins died due to an unrelated heart problem. The other, however, is living a normal life back in Germany.

Overall, Redett says, three-dimensional imaging capabilities are very important to the success of complex cases. “I think the field is wide open,” he says. “I have used it a lot on reconstructing cranial defects on children or adults after car accidents, gunshot wounds, or cancer. I get a 3D CT scan and send it out to be modeled; they make a piece out of titanium or polymer, and I can then implant that perfectly tailored piece into the person’s skull.” As this technology advances it is likely to be used for an increasing number of medical applications in the future. ■



一个由联体双胞胎医学图像与表面扫描制作出的实体模型，无组织扩张器，该图显示出他们联合颅骨的形状。外科医生在真正的分离手术前使用该模型进行练习
A physical model created from medical images and surface scans of the pair of conjoined twins, without tissue expanders, showing the shape of their combined skulls. Surgeons used this to practice on before the actual separation procedure