Serial	Time In	Time Out	Information
1	10:00:21:03		**VO: Surgeons have traditionally held a unique place in medicine. They have undergone decades of rigorous training, and are still revered as demi-gods in their profession. Every day thousands of people around the world put their lives in the hands of these skilled men and women. But waiting in the wings is something that may transform the surgeon's craft forever – robots.**
2	10:00:59:12		**VO: In June 2001, a revolution took place in medical history. It was called Operation Lindberg. The operation itself was straightforward enough – a gall bladder removal – but what made it unique was that the Surgeon was in America, while the patient was thousands of miles away in Europe.**
3	10:01:22:07		**VO: This pioneering surgery would not have been possible without the aid of a highly sophisticated remote-controlled Surgical Robot.** **The robot in France was connected by fibre optic cable to the console in New York. The Surgeon at the console manipulated the robot's arms to perform the operation in just under one hour.**
4	10:01:50:15		**VO: Remote surgery may be a headline grabber but these kinds of robots are also bringing huge improvements to everyday Surgical practice. St. Mary's Hosptial in London is one of a small group of hospitals worldwide exploring their potential.**
5	10:02:08:01		Darzi:. The robot, per say, is used no more than twice a week for clinical use. The rest of the time it is used for research purposes. So it is used within an environment of an experimental operating theatre.
6	10:02:22:12		**VO: But today the Robot is being used for surgery. the patient is 91 year old Sister**

			Marie Abernot. After consultation with darzi she has agreed that he can use the Robot in her operation
7	10:02:37:22		Darzi: we're operating on a very old patient who has a rectal prolapse, in other words, her bottom end is dropping out because of weaknesses in the muscles in that area. So we're going to go inside and with the Robot were going to, if you like, lift or hitch the bowel up and put a couple of sutures in to fix it to the bone. So it will prevent it coming down...she's had previous operations in her tummy so she might have some scarring inside but I don't anticipate any problems.
8	10:03:13:04		**VO: The robot Professor Darzi will be using in this case is called Da Vinci. Like the one used in operation Lindberg it has several articulated arms. One of these will hold a camera, with the others, the surgeon can dissect and suture.**
9	10:03:41:13		Darzi: what we're referring to here in Da Vinci is a master-salve manipulator...which allows you to do operations in a much more precise fashion. It actually controls not only the camera. but also simulates the surgical hands right hand and the left hand.
10	10:04:00:10		**VO: the robot can take a while to set up** Ok…could we have the...knife and ports.. do you see where I am...you're looking the wrong way....
11	10:04:27:16		**VO: The thought of a robot being used in operations may be disconcerting, but in some ways it's simply one more step in a process that's been going on for centuries.** **This is the quest for perfect precision.** Darzi – ok we're all ready – Shirley, yep? – You ready?
12	10:05:00:20		**VO: The earliest operating theatres were**

			crude affairs. A table in a room with sawdust on the floor to collect the blood. **With little or no anaesthetics, and very basic tools, surgery was a brutal art.**
13	10:05:27:07		**VO: But with the introduction of mechanical then electrical tools, it was slowly transformed.**
14	10:05:55:21		**VO: One of the biggest leaps in the search for precision surgery came in the early 80's with the invention of laproscopic, or keyhole surgery.** **In keyhole surgery, surgeons no longer had to make huge cuts in patient's bodies' – one of the main causes of post-surgical problems.** **But this also meant that surgeons were a lot more restricted in what they could do.**
15	10:06:20:20		darzi: from being an open operation, where you have to put your hands inside the Patient's tummy, we've substituted those in the era of keyhole Surgery by putting a camera system and two instruments. Now the camera system is a 2 d image – in other words we've lost the stereo. We've lost the 3D image, which is very important in surgery. And the second aspect of Surgery we've lost is the ability to manipulate the instruments inside, like you would do with your wrists and your hands.
16	10:06:55:15		Darzi (Actuality): The instruments are very rigid. I wouldn't have the articulation that I will have when I use the Da Vinci. In other words it's not as mobile.
17	10:07:05:19		**VO: This is the big advantage of da vinci. It gives the surgeons back that vital dexterity and vision**

18	10:07:13:04		Darzi: in contrast to the traditional keyhole surgery, which is 2D the Surgeon is able to see a 3D or Stereo image and that's a very important cue in the accuracy of the Surgeon performing an operation. The second difference is the instrumentation. The instruments used in the traditional key-hole surgery are like sticks, some people have described them as chop-sticks if you like, there is very little movement at the tips of these instruments except for the jaws to open and close.
19	10:07:45:23		Darzi: In contrast to the robotic instruments the tips of these instruments actually move in 6 different angles and this is what we call 6-degree freedom of movement. What we're really saying, they move exactly the same way as the human wrist would move. Now that has, obviously, huge advantages because the operating surgeon will feel that he has his or her wrist inside that cavity where they're operating on.
20	10:08:14:16		Darzi (actuality): so, I don't know if you can see the screen See the movements? – Yes? These are fully articulated 6-degree freedom of movement and I'm in full control now of the camera, which I'm bringing back. The views that I have down here are absolutely magnificent
21	10:08:40:12		Darzi: the robot could do things, which we were able to do before but much more precisely. And also it enhances the ability of the operating surgeon to do some technical aspects of the operation significantly better.
22	10:09:00:02		Rockall: by using those little endo wrists at the end of the instruments its almost like having your hands in side the abdomen. And the very high quality magnified 3 Dimensional vision means complicated things like tying knots and complicated dissection is made much easier.
23	10:09:21:20		**VO: These are not the only advantages. The surgeons can now perform non-invasive**

			operations that they couldn't before. **And it makes a difference to the patient – recovery times are generally quicker when the surgery is Robot-assisted.** **But the surgeons hope to make Da Vinci even better with the help of British engineers.**
24	10:09:45:23		**Brian Davis is the chief engineer working with Darzi's team who will be developing the next generation of Da Vinci. The research for this project has only just begun, but in the meantime, Davis has been perfecting his own master slave robot**
25	10:10:01:23		Davies: this is the Acrobot Robot, which is used for total knee replacement.
26	10:10:10:19		**VO: This operation involves cutting the femur to exactly the right shape so that the replacement knee joint or prosthetic implant can fit properly.**
27	10:10:21:16		Davies: these are the prosthetic implants which are used on the knee so what we do is make a sequence of five straight line cuts to sit this very accurately aligned onto the end of the Femur. We seat down this Tibial component right onto the end of the Tibia and align the two very accurately one with respect to the other. when the surgeon uses conventional instruments, the fit of the Prosthesis and the alignment with the Tibial component is not as exact as you might like it.
28	10:11:01:11		**VO: If a knee joint is badly aligned it can cause serious problems. Too much load on one side of the implant will cause premature wear and tear and the implant won't last. This can also cause a lot of pain.** **The robot is designed to prevent this by stopping the surgeon from cutting in the**

			wrong place. To make sure the robot knows the correct position of the cuts, a pre-operative plan is made from scans of the patient's knee.
29	10:11:35:19		Davis: that plan is then passed as a series of cutting constraints and motions to the Robot. On the day of the operation the patient wheeled in to the Operating Room and then we clamp the leg down, and then we operate on that knee as if its a fixed object from then on. Now what we have to do is make sure we are orientated correctly with our pre-operative plan.
30	10:12:07:12		**VO: To do that the tip of the robot is touched to a series of anatomical features on the knee. This ensures that the robot knows exactly where the patient's knee is, in relation to the pre-operative plan.**
31	10:12:42:15		**Now the robot is ready to cut.** **In theory, Acrobot could have been produced to do this part of the procedure automatically with the surgeon simply doing the fine adjustments at the end.**
32	10:12:57:00		DAVIES: We felt that that was not acceptable to surgeons who are really trained to have their hands on the patients so what we've done now is to put a lever on the end of the robot arm and whilst the Surgeon is there, holding the lever, he is in direct control of the system. We have a high speed rotary cutter on the end which is cutting the bones and we have the Robot acting as a constraining influence so that as he moves down, he is allowed to move in certain regions and not allowed to move beyond the particular level of the cut on the end bone of the knee.
33	10:13:44:04		Davies: And we can get results so that the angle of orientation is better than one degree to what you planned and better than one millimetre in gap. Typically on normal Surgery that goes to five, maybe nine degrees and five millimetres. And to some extent an average Surgeon can consistently achieve the results of

			a very skilled surgeon on his best day.
34	10:14:16:09		**VO: Both da vinci and Acrobot may help surgeons to achieve better results, but they still have one big disadvantage in comparison to their human masters – they have no sense of touch.**
35	10:14:29:08		**Unlike this robot, called Bloodbot, which does have a rudimentary ability to feel. It's a very simple unit, which is designed to take blood samples from a vein. Like the Acrobot the aim was to make this invasive procedure more precise. Unlike Acrobot, it has no pre-operative plan to work from but has to react to what it feels.**
36	10:14:54:02		Dr.Zivanovich: Bloodbot works by imitating the way a Nurse finds a vein in your arm. It uses a sense of touch rather than any other sense. So it scans across the width of the arm pressing against the surface of the skin and by the way that skin reacts to that touch….it tells .tells when there's a vein present. Once its found a vein, it returns to that position with a needle and pushes the needle in. And it knows its reached a vein because of the way the vein wall gives way as you push a needle through it. There's an initial resistance, which drops as the needle pushes through. And this is in fact how Nurses know that they've hit a vein also.
37	10:15:33:11		**VO: Bloodbot's sense of touch is essentially an ability to detect and react to changes in its environment. This is one of the most important nuts to crack in the production of autonomous robots.**
38	10:15:58:23		**All these research projects at Aston University in Birmingham are trying to solve the same problem – how to make machines recognise and react to changing cicumstances. This team is led by professor Peter Brett; a world expert in this technology.**
39	10:16:17:17		Brett: The pressure in general for Surgery is to work through smaller and smaller holes, more

			and more difficult access and when that happens the surgeon loses a lot of sensation, and we'd like to sort of reinstate that for surgeons as far as possible.
40	10:16:35:18		**VO: Brett has developed a robot to do just that – to effectively 'feel' what the Surgeon can't.**
41	10:16:48:07		**He began by asking ENT surgeon Mansel Griffiths in Bristol, to work with him on the project.**
42	10:16:54:24		Griffiths: I think at that time, in fact, I happened to be actually doing, uh, a Stapedectomy operation, which is one of these operations that we actually do, uh, to improve patients hearing and that's really where it took off because there were some technical difficulties that we encountered uh, with that type of surgery, uh, and, uh, we thought, well let's look at this aspect in the first instance.
43	10:17:23:06		Griffiths: The stapes operation is to treat a condition called Otosclerosis. This is a condition where the bones in the middle ear fuse together and in that way you fail to get any transmission of sound.
44	10:17:43:04		**VO: To remedy this, the surgeon removes part of the Stapes bone, drills a hole through the Stapes footplate and inserts a small prosthesis. This will allow sound to be transmitted once more. But the operation is not without risks.**
45	10:18:05:06		Griffiths: – You're working very very closely to the inner ear, which is this part here, and if you damage the inner ear then in fact you produce a permanent hearing loss.
46	10:18:19:09		**VO: Surgeons believe that such damage is most likely caused when drilling the hole through the stapes footplate.**
47	10:18:28:08		Griffiths: the surgery is actually done, if anything at all rather crudely, using little, picks, and then when you come down to the bottom part of the Stapes itself which is called the footplate uh, then you have to actually drill

			that out.
48	10:18:50:07		Brett: now the surgeon's faced with working through a difficult access. He has no idea how thick the stapes is. It can be anything from point one of a millimetre thick to 2.5 mm thick. And of course as he makes a hole –whether its drilling or with picks the stapes will flex.
49	10:19:09:12		Griffiths: I think, the comparison that one can draw, is, that when you're drilling through a piece of wood you can actually look the other side of it, to actually see, in fact what is happening, uh, unfortunately, when it comes to the ear, you have no idea at all where the other side is. The other point with respect to wood is that as you press on it with a drill then that in fact will actually deflect the wood a little. But then as you come through the other side, the wood then actually goes back to its original position, and you're left with, you know, the drill protruding through.
50	10:19:58:13		Brett: and it means that the important membranes behind could easily be penetrated and it is reckoned that is a cause of the failure of this procedure in practice. So this drill we've developed is a solution that will detect the far surface and withdraw quickly in such a way that penetration either doesn't occur or occurs to the degree you wish.
51	10:20:21:21		**VO: Developing the drill was not straightforward. Brett's task was to mechanically reproduce the Surgeon's delicate sense of touch – something the Surgeon takes for granted.**
52	10:20:35:18		Brett: surgery is very much an art and engineering is very much a science and so we approach things from a slightly different angle.
53	10:20:43:03		Mansell: for instance, of the sort of question that was, uh, asked of me, uh, is, well, using the conventional method, what sort of force do you actually use in order to break through the Footplate. And my answer to that was, well, you know, you do that –

			And he said, no he said, no how much is it in Newtons?
54	10:21:08:03		Brett: so we then had to carry out a number of different experiments where we were trying to judge what a newton probably felt like!
55	10:21:18:23		**VO: Once Brett had measured the forces involved, he had to find out if it was possible to automate this delicate procedure.**
56	10:21:28:20		Brett: what we did was we drilled many bone specimens to see what happened. The repeatable thing which happened on breakthrough was there was some special transients in the force and torque that happened only in that condition and together. As a result of that we were able to find a way of detecting that in the signals, and that enabled the whole process to be automated.
57	10:21:52:06		**VO: Brett had found a pattern that occurred during drilling which was the same no matter what the size of the bone.** **When the drill is just about to break through the bone, the force drops off, and the torque increases.** **When these two events occur, the drill stops and retracts. It then moves forward again, to perform a very slow and controlled breakthrough.**
58	10:22:23:01		Brett: if you were to drill this manually, then an expert surgeon would probably overshoot the far side of the bone by about a millimetre. The drill itself does not protrude more than point zero two millimetres so it's actually a 50^{th} or better.
59	10:22:45:03		Griffiths: An experienced surgeon doing conventional surgery can do this type of surgery, you know, very efficiently and very rapidly, but at the same time we do know that with a piece of equipment, a robotic tool that's been programmed properly and is working efficiently that the chances of actually

			producing in fact a better end result, uh, is there.
60	10:23:16:09		**VO: No matter how much better robots might be it's highly unlikely that they will replace surgeons in the operating theatre.** **However, it is possible that the surgeon's role will come under threat from a very different kind of robot – one created by nanotechnology.**
61	10:23:32:18		Snowdon: nanotechnology is defined in terms of the scale so it refers to any manipulation of materials devices, which are on the scale of about 1millionth of a mm.
62	10:23:47:13		**VO: Newcastle University has been granted funds to set up a state of the art Centre for Nanoscale Technology.** **Here, a multi-disciplinary team of research scientists is hoping to create nano-sized surgical robots, so precise they will be operating at the level of a single cell.**
63	10:24:06:06		Snowdon: The nature of the robot which we might be use is an again an unconventional robot, it doesn't have knives, it doesn't cut, it doesn't take material in, in the normal sense and replace it. What we envisage is a device which would seek out and identify and destroy cells, organisms defects which at the present time require invasive surgery.
64	10:24:35:03		**VO: These nanorobots will probably be engineered from both man-made and biological structures. In an ingenious solution to the problem of propulsion, for example, the robot might be given one of nature's own motors, from bacterium.**
65	10:24:50:21		Snowdon: E-coli for example has a whip-like tail very similar to a mechanical bearing and that allows E-coli to actually move within bodily fluids. We can now use elements like that for propulsion. We can now extract such motors from bacteria and use them in new

			settings
66	10:25:18:07		**VO: The eyes and ears of these particles will also come from biological systems.** **Nano-robots could perform all kinds of operations. It will still be surgery, but not as we know it today**.
67	10:25:32:04		Snowdon: nanotechnology is going to change surgery and its going to take us away from the idea of surgery as a physical knife and replace it by the atomic or molecular scale equivalent.
68	10:25:52:02		**VO: Knee replacement operations might become a thing of the past. Where the old joint is worn out or diseased, the nano robots will simply help our bodies to grow a new one.**
69	10:26:05:15		**So what of the future of surgical robots? The history of robots so far has been driven by the constant search for improvement.**
70	10:26:15:04		**One hundred years ago, surgeons would have to cut off an entire leg to deal with a particular problem.** **Today, with the help of master slave and autonomous robots they can perform minimally invasive surgery through tiny holes in the skin.** **Tomorrow the surgical invasion might be as small as a pin-prick – a mere injection of tiny particle robots, operating with the kind of precision and effectiveness that today's surgeons can only dream of.**
71	10:26:44:05		Darzi: You're really looking at the start of this concept in surgical practice

Credit List for Hand-Stitched by Robots

INDIVIDUALS:

Professor Peter Brett
Professor Ara Darzi
Professor Brian Davies
Mr. Mansel Griffiths
Doctor Gordon Hughes
Mr. Tim Rockall
Professor Ken Snowdon

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The Centre for Nano-Scale Technology, Newcastle University
David Lloyd Racquet and Fitness Club
Imperial College, London
Intuitive Surgical, USA
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St. Mary's Hospital, London
St. Michael's Hospital, Bristol
The Old Operating Theatre, London
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Executive Producer: James Butterworth

Series Producer: Ron Blythe

Music Cue Sheet for Hand Stitched by Robots

Serial	Time In	Duration	Track Title	Composer	Publisher
1	10:00:19:24	29 seconds	'Heart Beat'	Dillon Rendell (FTA Employee)	Film & TV Associates
2	10:00:56:22	1 min 1 sec	'Pulse'	Dillon Rendell	Film & TV Associates
3	10:04:22:01	29 secs	'Heartbeat'	Dillon Rendell	Film & TV Associates
4	10:04:49:21	1 min 2 secs	'Hubble'	Dillon Rendell	Film & TV Associates
5	10:07:59:10	1 min 47 secs	'Zeus'	Dillon Rendell	Film & TV Associates
6	10:10:08:10	16 secs	'Fusion'	Dillon Rendell	Film & TV Associates
7	10:10:44:00	1 min 3 secs	'Fusion'	Dillon Rendell	Film & TV Associates
8	10:12:02:23	44 secs	'Heart 1'	Dillon Rendell	Film & TV Associates
9	10:13:36:09	15 secs	'Pulse'	Dillon Rendell	Film & TV Associates
10	10:15:31:20	15 secs	'Cross Stitch'	Dillon Rendell	Film & TV Associates
11	10:15:41:11	44 secs	'Robotic Exploration'	Dillon Rendell	Film & TV Associates
12	10:16:28:23	26 secs	'Robotic Exploration'	Dillon Rendell	Film & TV Associates
13	10:17:17:09	53 secs	'Exploration Inside'	Dillon Rendell	Film & TV Associates
14	10:18:12:01	30 secs	'Extreme Theme'	Dillon Rendell	Film & TV Associates
15	10:19:52:11	19 secs	'Exploration Inside'	Dillon Rendell	Film & TV Associates
16	10:21:15:02	29 secs	'Pulse'	Dillon Rendell	Film & TV Associates
17	10:21:45:14	1 min 17 secs	'Cross Stitch'	Dillon Rendell	Film & TV Associates
18	10:23:13:20	1 min	'Cross Stitch'	Dillon Rendell	Film & TV Associates
19	10:24:19:00	39 secs	'Robotic Exploration'	Dillon Rendell	Film & TV Associates
20	10:25:16:23	30 secs	'Robotic Exploration'	Dillon Rendell	Film & TV Associates
21	10:25:38:01	1 min 25 secs	'Cross Stitch'	Dillon Rendell	Film & TV Associates