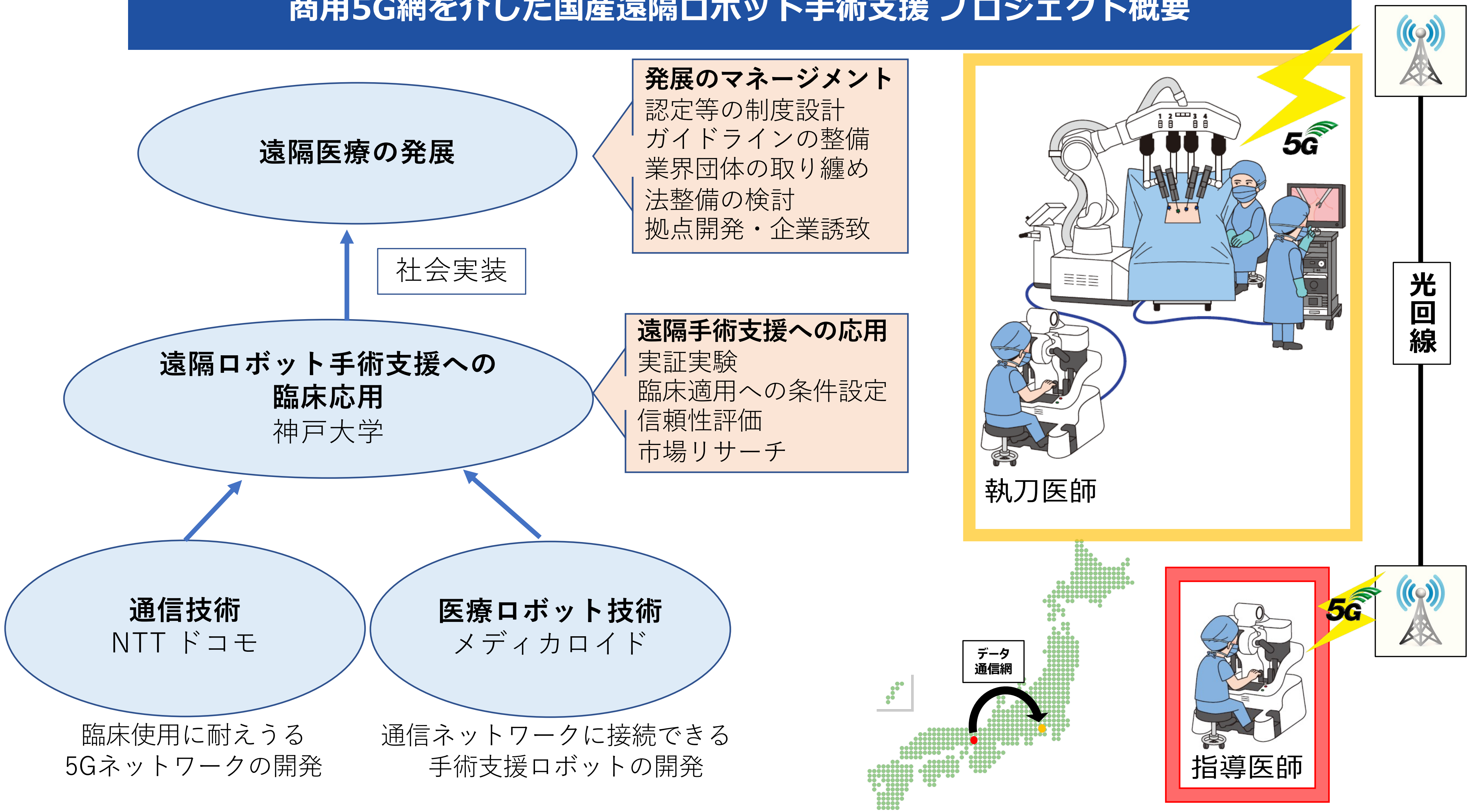
商用5Gネットワークを介した 国産手術支援ロボット“hinotori™” による遠隔手術の試み

神戸大学大学院医学研究科外科学講座
山口　雷藏

商用5G網を介した国産遠隔ロボット手術支援 プロジェクト概要



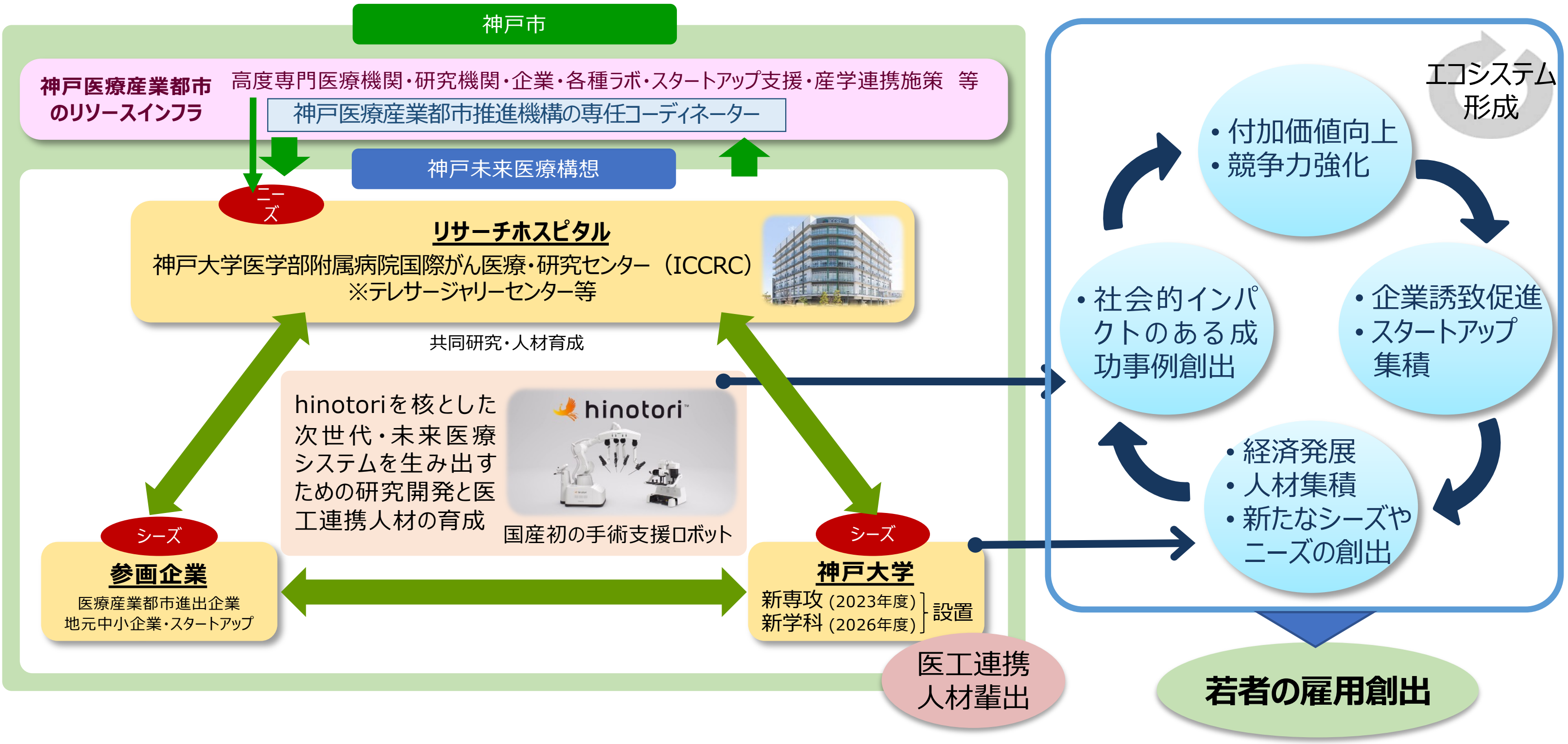
神戸未来医療構想の事業概要

2020年度より内閣府、神戸市による地方大学・地域産業創生交付金 事業として、

・研究環境整備事業：ICCRC，ＭｅＤＩＰを中心とした拠点整備

・研究開発事業：手術のデジタル化によるデーター医療産業の創出、**遠隔ロボット手術の技術開発**

・人材育成事業：医工連携人材の育成のための新専攻・新学科の設置



本日の内容

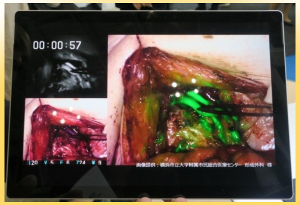
- 手術ロボット開発のキーワードはナビゲーション
- 手術ロボットとデジタル情報
- 遠隔ロボット手術は今
- 最近の競合国の動き
- 将来への発展性

今後のロボット支援手術の発展性

3つのNavigation

① がん細胞標識、分子イメージング、レーザー顕微鏡、8K内視鏡等によるハード面からのナビゲーションアプローチ
② 集められた莫大な医療情報をAI等で解析し、手術技術の評価、指導といったソフト面からのナビゲーションアプローチ
③ ５Gによる機械間、病院間でのデータネットワークを確立することによって様々な情報を開発センターへ収集するとともに、開発センターからの遠隔操作等によるナビゲーションアプローチ

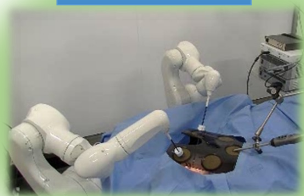
1）癌可視化



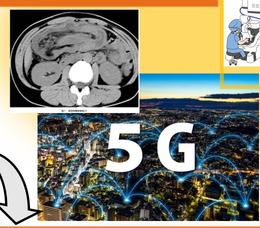
がん細胞標識、分子イメージング、レーザー顕微鏡、8K内視鏡によるNavigation System

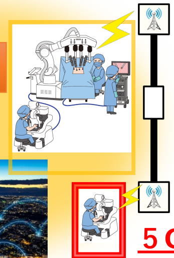
標的可視化による精緻手術ナビゲーション

Hinotori™



3）デジタル通信





５Gネットワーキングを活用した遠隔検査、遠隔指導・遠隔手術、アノテーションシステム

５G通信による遠隔診断・手術ナビゲーション

2）AIによる手術評価・補助

手術画像データ・ログ解析に基づく手術評価・補助、自律制御ロボット

AIによる最適手術ナビゲーション

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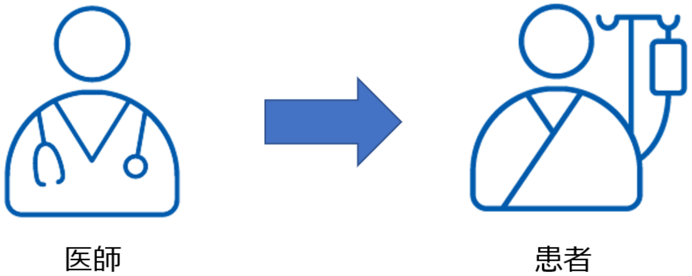
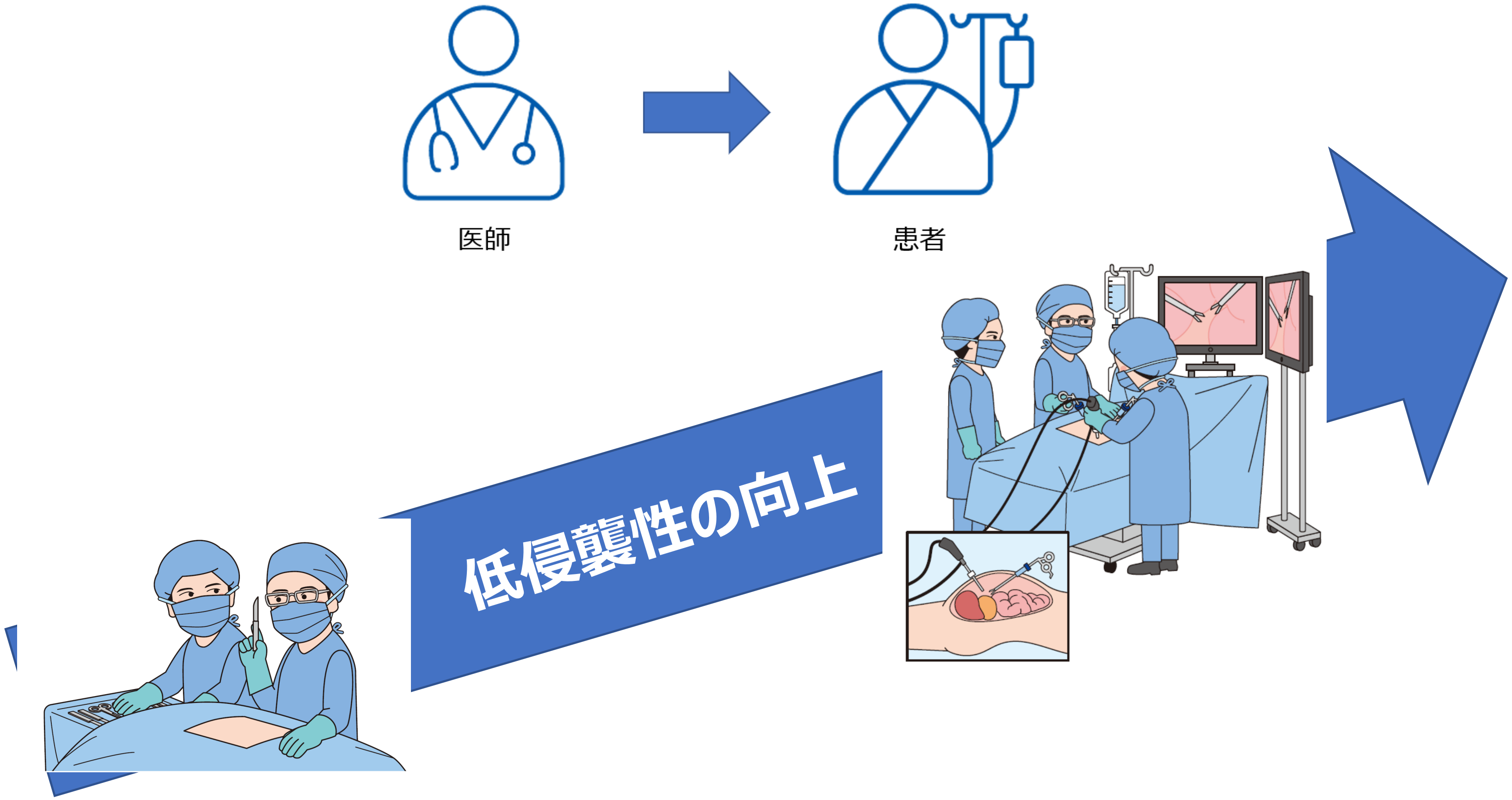
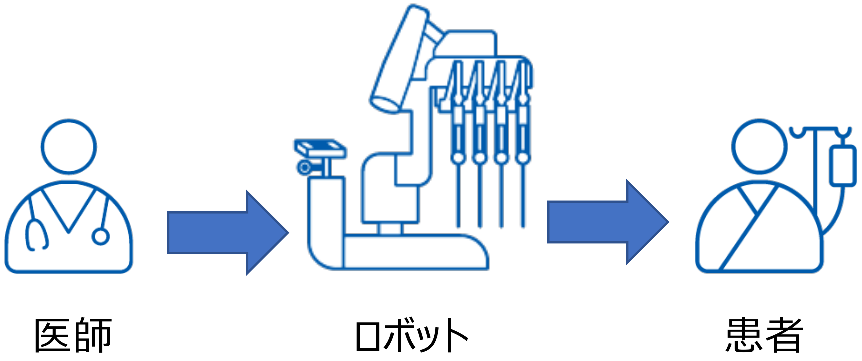
開腹手術

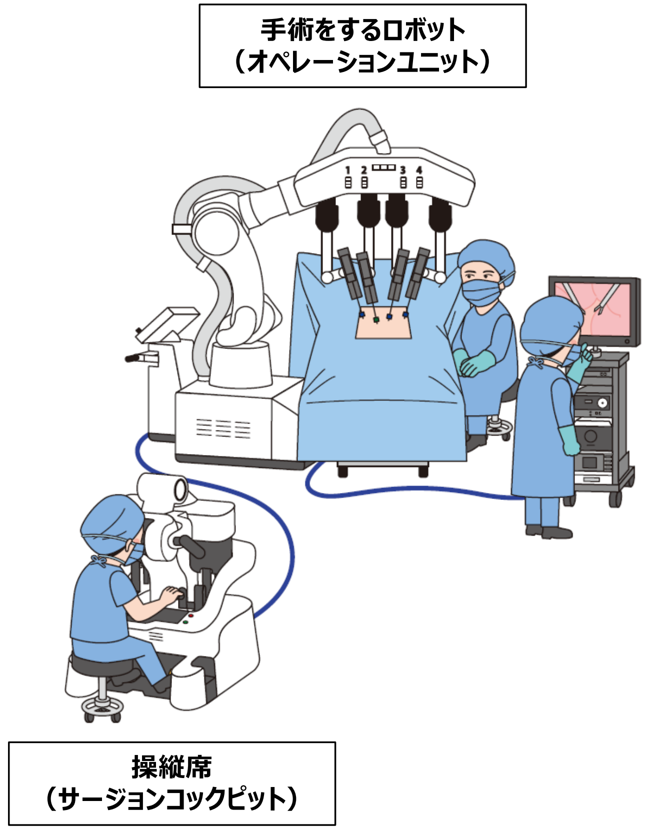


内視鏡下手術



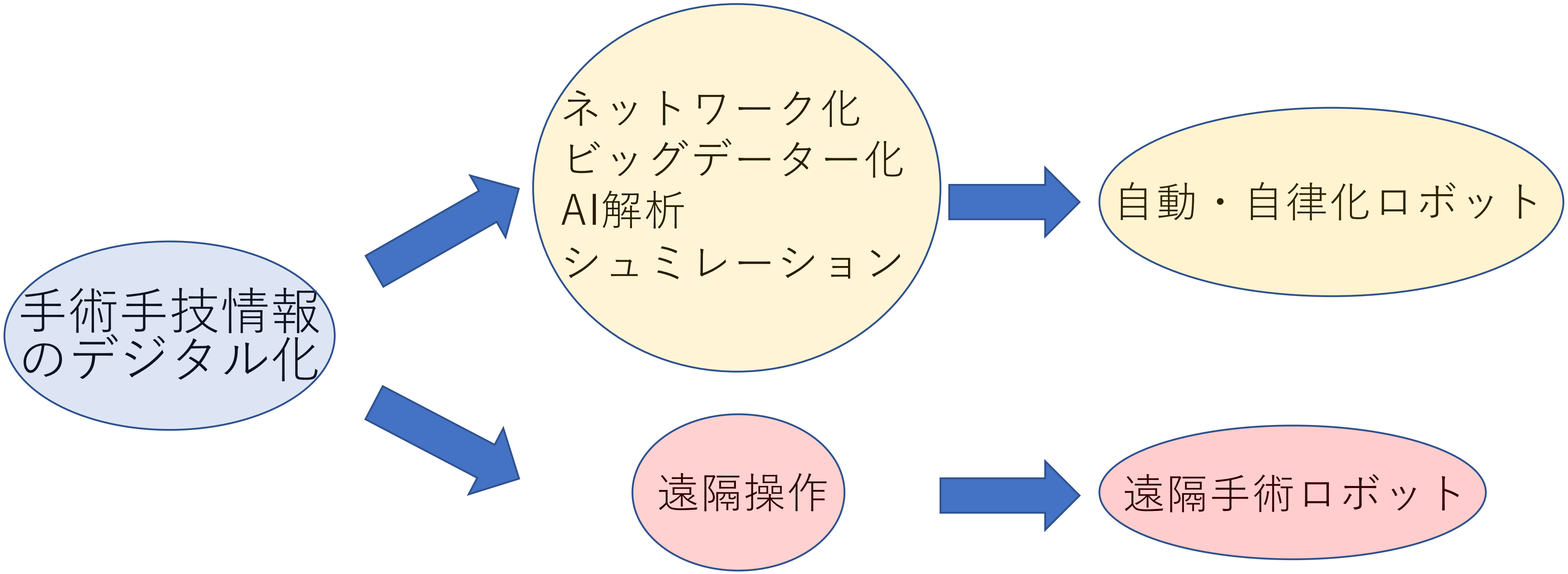
ロボット支援手術



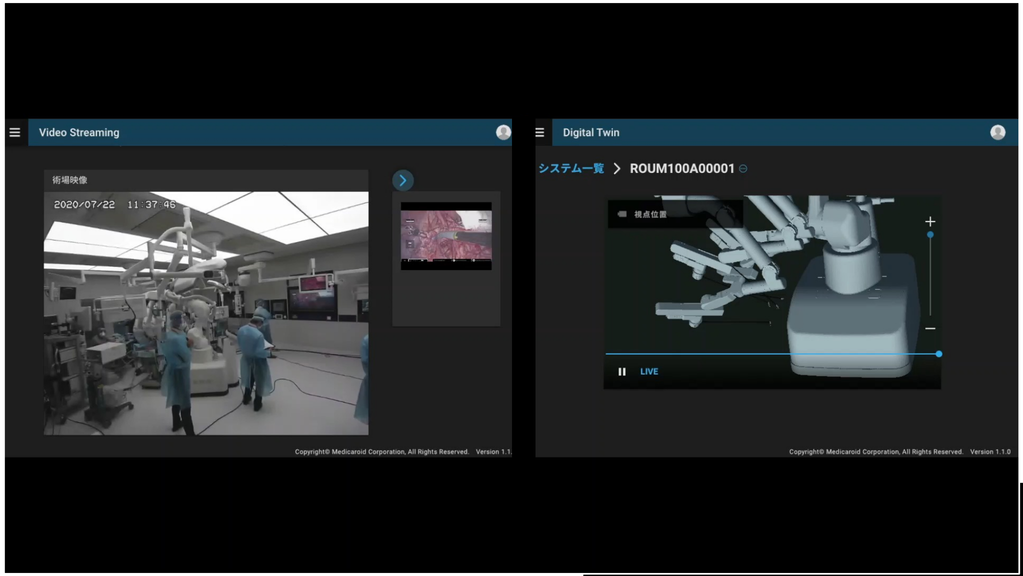


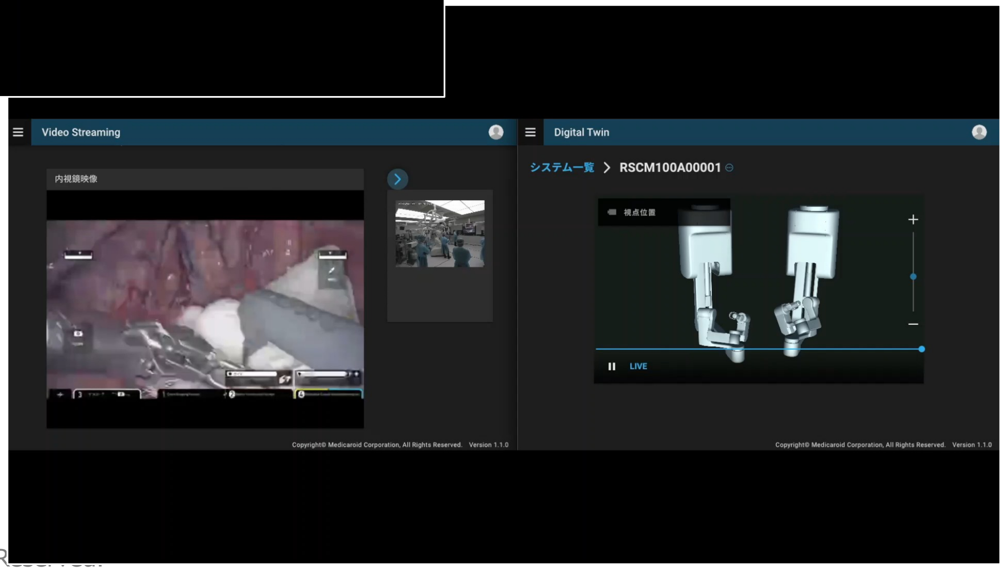
アナログからデジタルへ

手術手技のデジタル化がもたらしたもの



ロボットの動作をリアルタイムに再現（Digital Twin）





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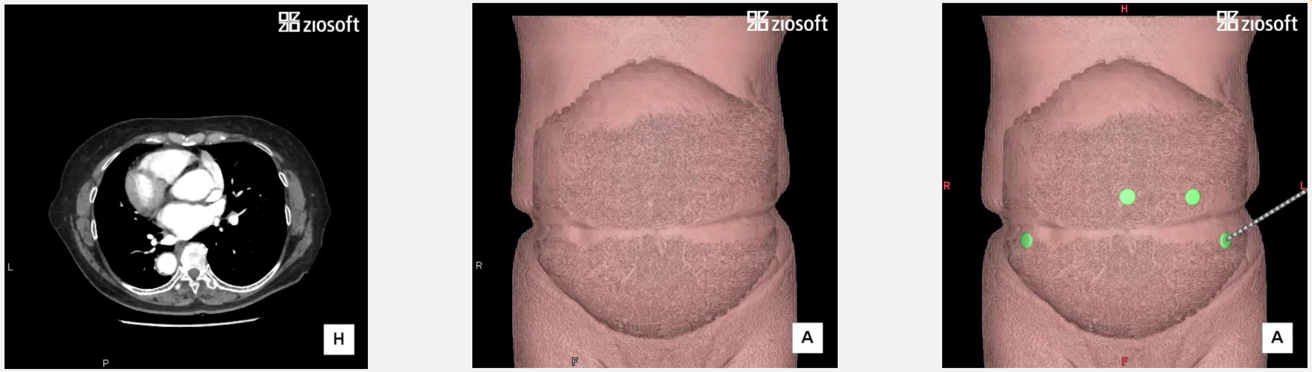
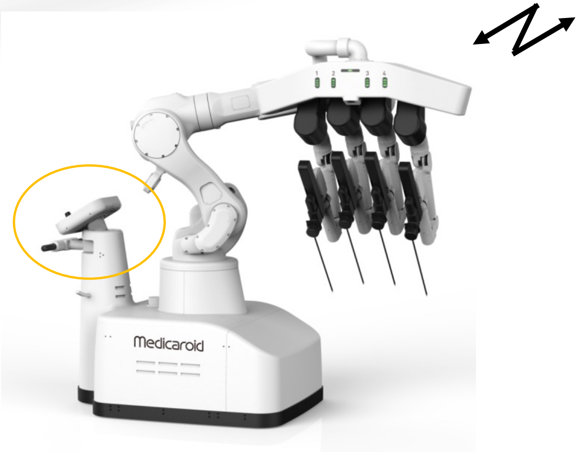
術前手術計画～ポート配置シミュレーション～



術前ポートシミュレーションを手術に反映

※表示画像は
イメージです

MINS



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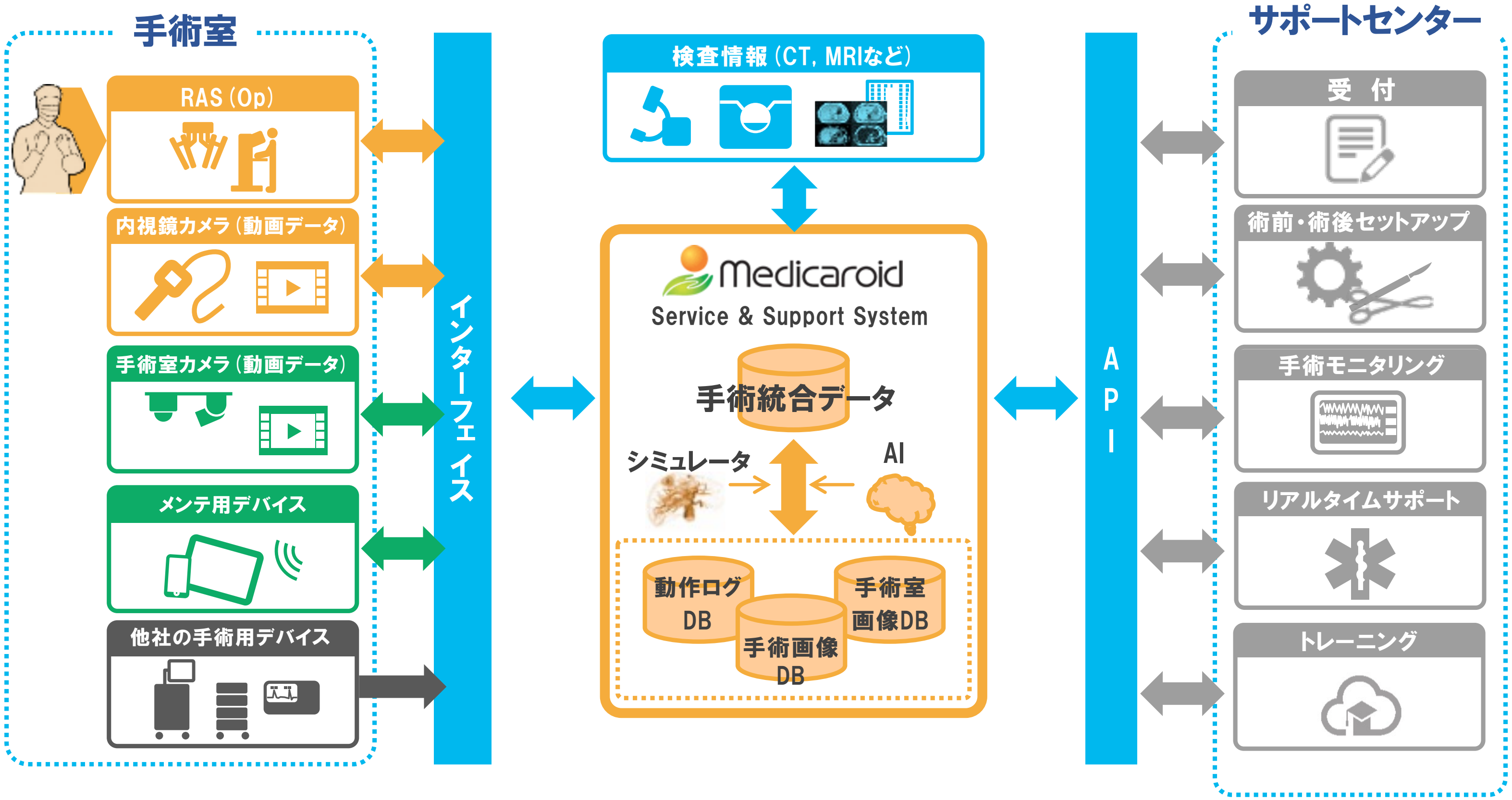
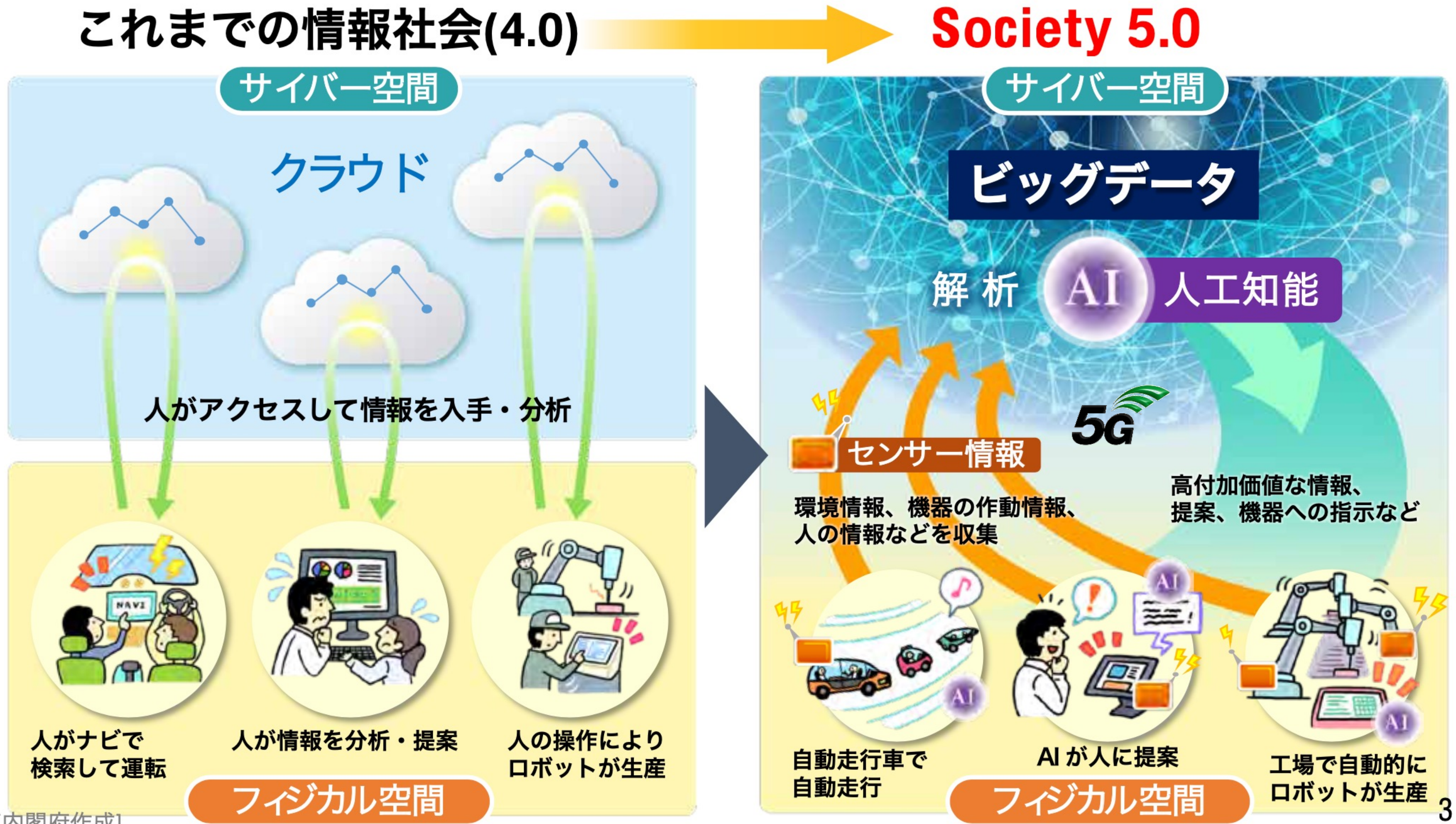
ネットワークサポートシステム

Medicaroid Intelligent Network System （MINS）



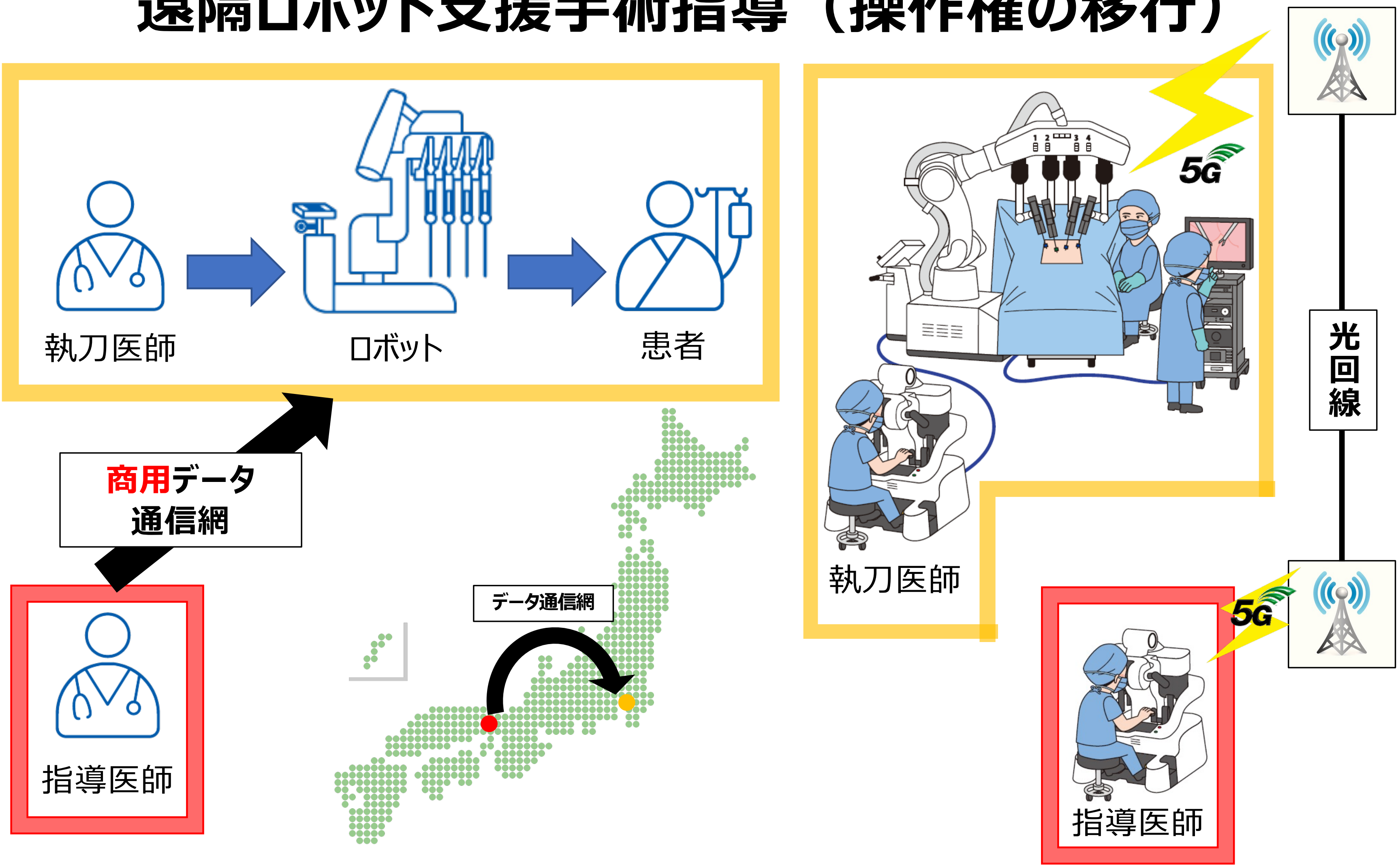
サイバー空間とフィジカル空間の高度な融合

フィジカル（現実）空間から**センサー**と**IoT**を通じてあらゆる情報が集積（**ビッグデータ**）
人工知能（AI）がビックデータを解析し、高付加価値を**現実空間にフィードバック**



[内閣府作成]

遠隔ロボット支援手術指導（操作権の移行）



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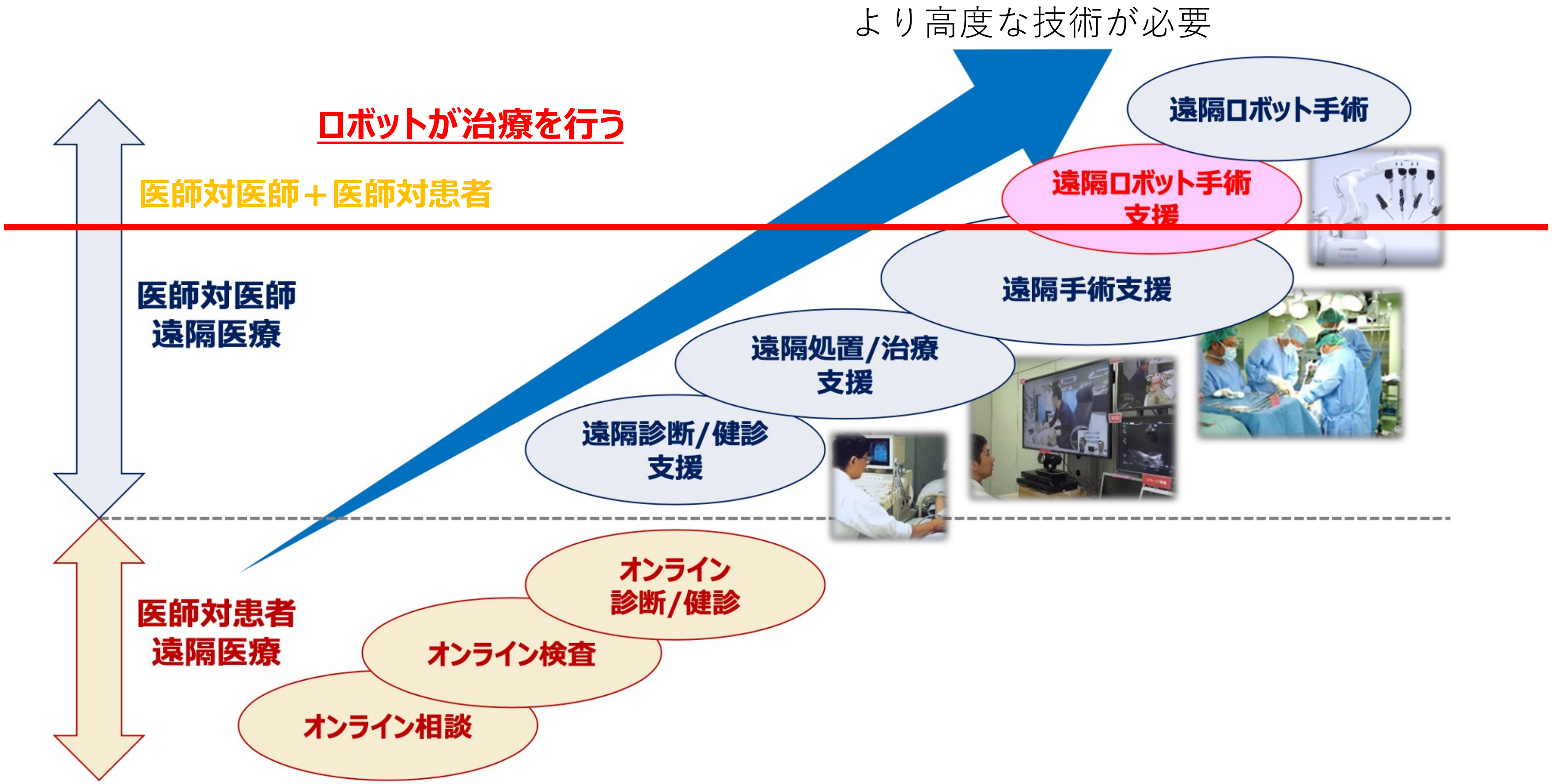
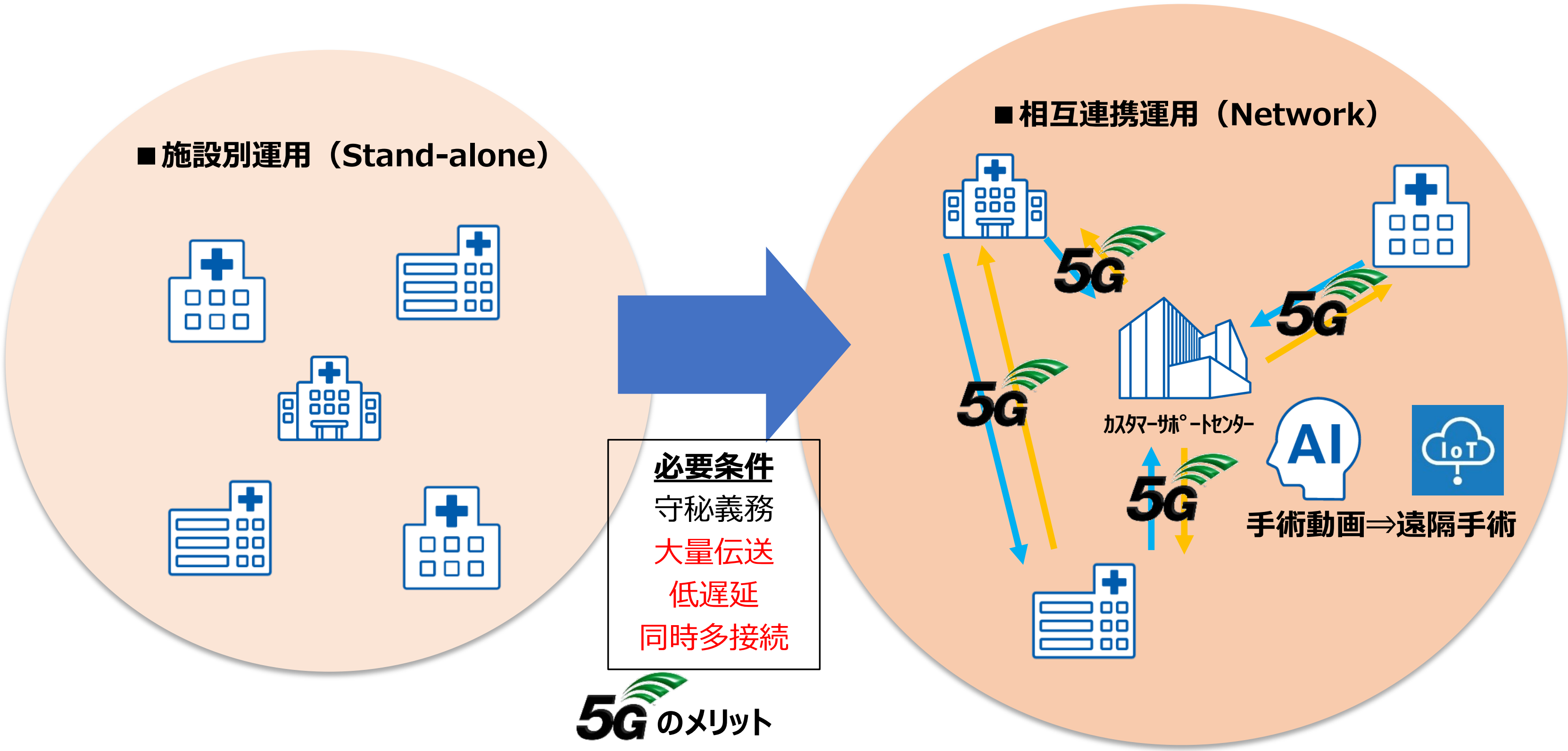
モバイルネットワークを活用する遠隔医療



デジタル通信の目指すところ

施設とロボット間、ロボット相互間をネットワーク化し、
医療情報の共有と遠隔でナビゲーションが行える仕組みの構築



5G Telemedicine & Medical Training

The purpose of this article is to inform about exciting activities and future visionary events taking place to enhance Department of Defense (DOD) medical support capabilities within the developing 5G core environment.

In June 2020, Office of the Undersecretary of Defense (Research & Engineering) named Joint Base San Antonio (JBSA) as an experimentation site for 5G augmented reality support for telemedicine and medical training. Although telemedicine is already happening today, it is often inhibited by a lack of adequate digital connectivity supporting the data speeds and volumes needed to provide real-time virtual healthcare. Since 5G is a critical strategic technology, the DOD must master 5G networks, which will eventually touch every mission and operation of DOD medicine.

The joint DOD telemedicine community has identified seven key goals that 5G solutions must address:

Goal 1: Save lives and maximize preventive medicine.
Goal 2: Provide resilient and fault-tolerant medicine and medical services anywhere in the world to support U.S. national interests and maintain military mission assurance.
Goal 3: Collapse time and space to achieve real-time virtual and digital medical support.
Goal 4: Extend medical expertise forward to the operational edge to enhance support for mobile forces in operational or austere environments.
Goal 5: Ensure mission and data security in all medical applications.
Goal 6: Maintain an environment which allows DOD medicine and medical services to practice virtual medicine to the maximum state possible.
Goal 7: Provide an environment that facilitates the injection of new technologies in support of telemedicine applications.

5G Advanced Telerobotic Surgery

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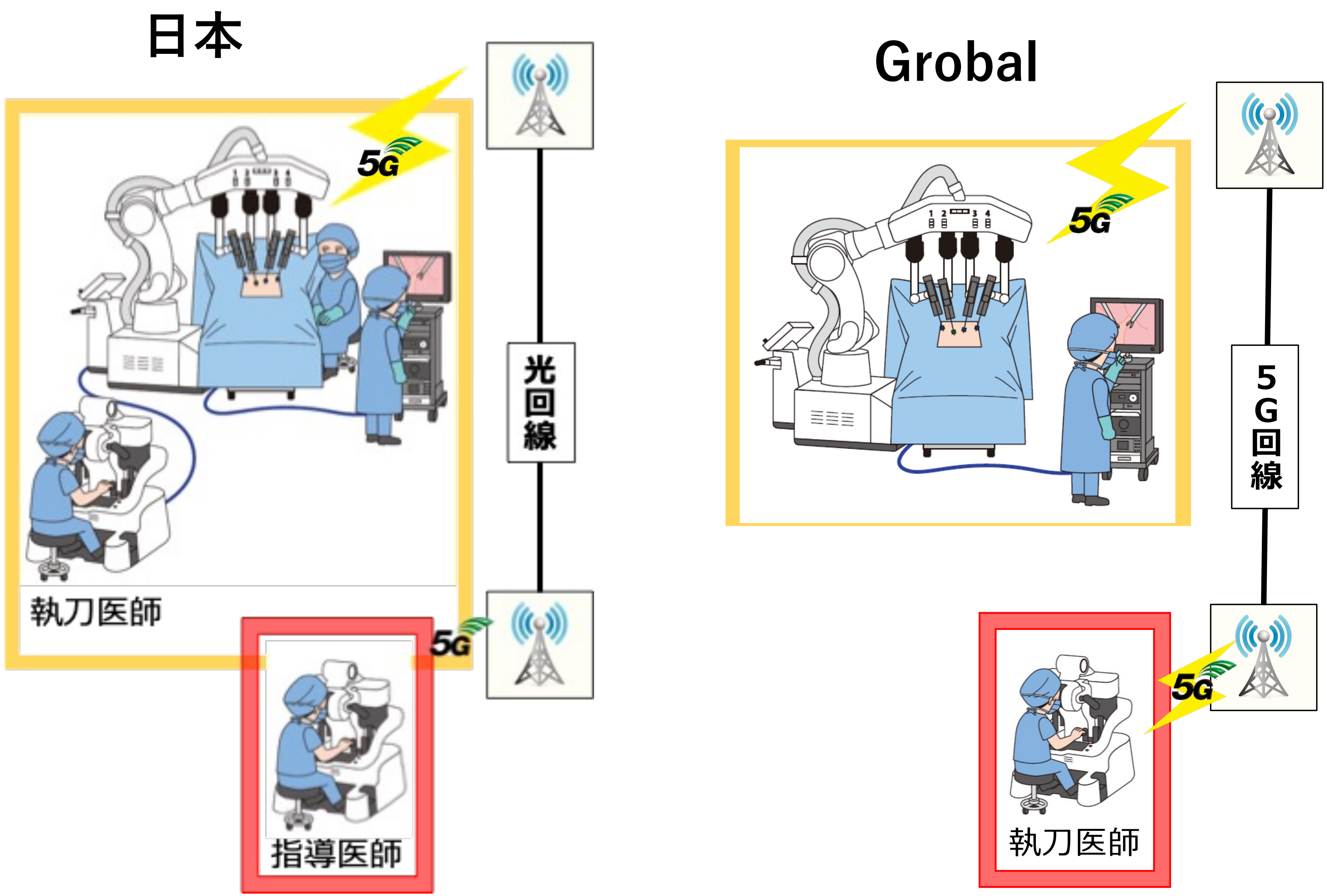

日本
5G
光回線
執刀医師
5G
指導医師
Grobal
5G
5G回線
5G
執刀医師

OXFORD

Short Report

BJS, 2023, **110**, 6-
https://doi.org/10.1093/bjs/znac27
Advance Access Publication Date: 23 August 202
Short Repo

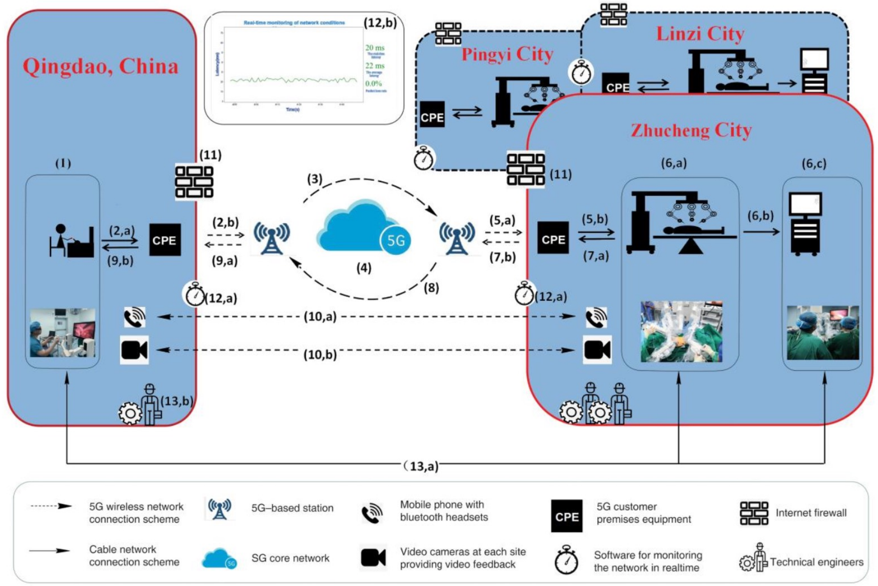
Telerobot-assisted laparoscopic adrenalectomy: feasibility study

Jianmin Li[1], Wei Jiao[2], Hang Yuan[2], Wei Feng[3], Xuemei Ding[4], Xulong Yin[5], Liangjun Zhang[6], Wei Lv[7], Lufei Ma[8], Liguo Sun[8], Run Feng[9], Jun Qin[10], Xuefeng Zhang[11], Chengyi Gou[12], Shuxin Wang[1], Zongyi Yu[13], Bin Wei[14], Lei Luo[2], Fei Xie[2], Yuan Chang[15], Yonghua Wang[2,*], Pier C. Giulianotti[16,*], Qian Dong[17,*] and Haitao Niu[2,*]

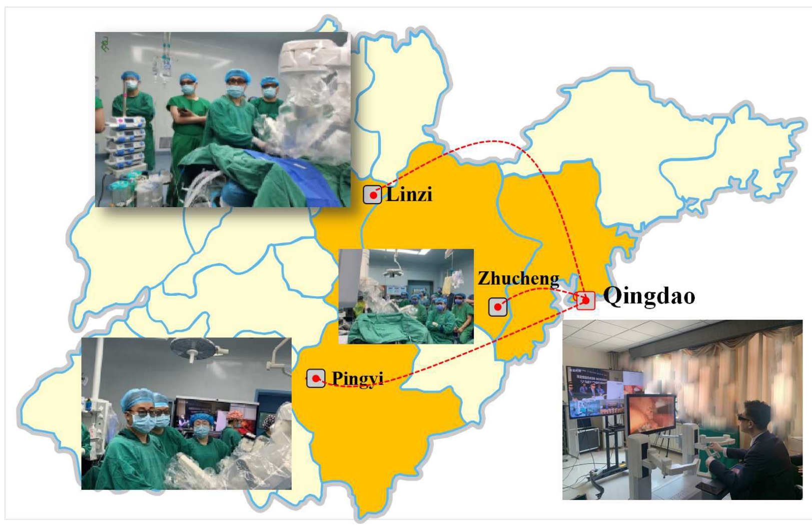
Table 1 Detailed intraoperative network communication and surgical outcomes of telerobot-assisted laparoscopic adrenalectomy

Patient	Network communication				Surgical outcomes				
	Distance (km)	Network latency (ms)	Total latency (ms)*	Network-related adverse events	Duration of teleoperation (min)	Blood loss (ml)	NASA-TLX score	Clavien–Dindo grade	Pain score at 24 h (VAS)
1	250	54	204	2	60	35.66	72	I	2
2	82.5	43	193	0	85	68.47	72	I	1
3	199	30	180	1	58	24.32	72	I	5
4	199	32	182	1	45	4.85	97	I	3
5	199	29	179	0	73	52.40	76	I	3
6	82.5	27	177	0	42	17.69	43	I	1
7	250	35	185	0	38	27.02	52	I	1
8	250	31	181	1	34	22.32	90	I	1
9	250	30	180	0	49	35.63	66	I	1
10	250	34	184	0	42	26.20	67	I	1
11	82.5	22	172	0	44	3.07	71	I	1
12	82.5	23	173	0	47	20.30	72	I	2
13	250	32	182	1	70	13.42	46	I	1
14	250	32	182	0	21	10.35	44	I	1
15	250	34	184	0	21	22.77	35	I	2

*The total latency (tl) includes network latency (nl) and the time for the robot system to process the signal (tr): tl = tr + nl. The tr was approximately 150 ms, including the servo period of the surgical robot (less than 1 ms), the mechanical response delay of the robot (40 ms), endoscopic imaging, image processing delay (50 ms), and the video codec delay (60 ms). NASA-TLX, National Aeronautics and Space Administration Task Load Index; VAS, visual analogue scale.



1 Equipment and network for telerobot-assisted laparoscopic adrenalectomy



In space, robots could someday make housecalls for doctors far from astronauts. Virtual Incision Corp. last week announced that it will test its MIRA surgical robot's skills in a 2024 technology demonstration mission aboard the International Space Station, or ISS.

The Robotics Applications Conference from Robotics 24/7.

August10,2022

RAC Homepageより転載

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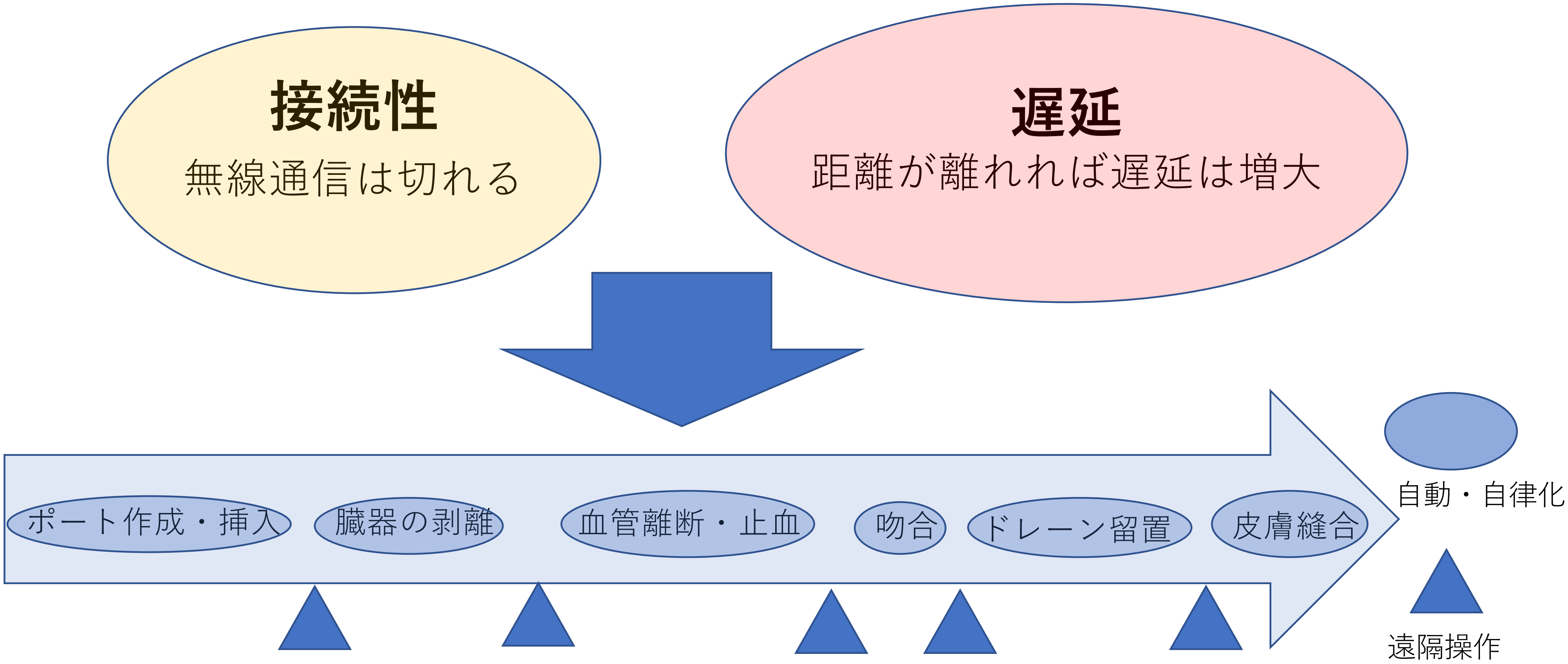
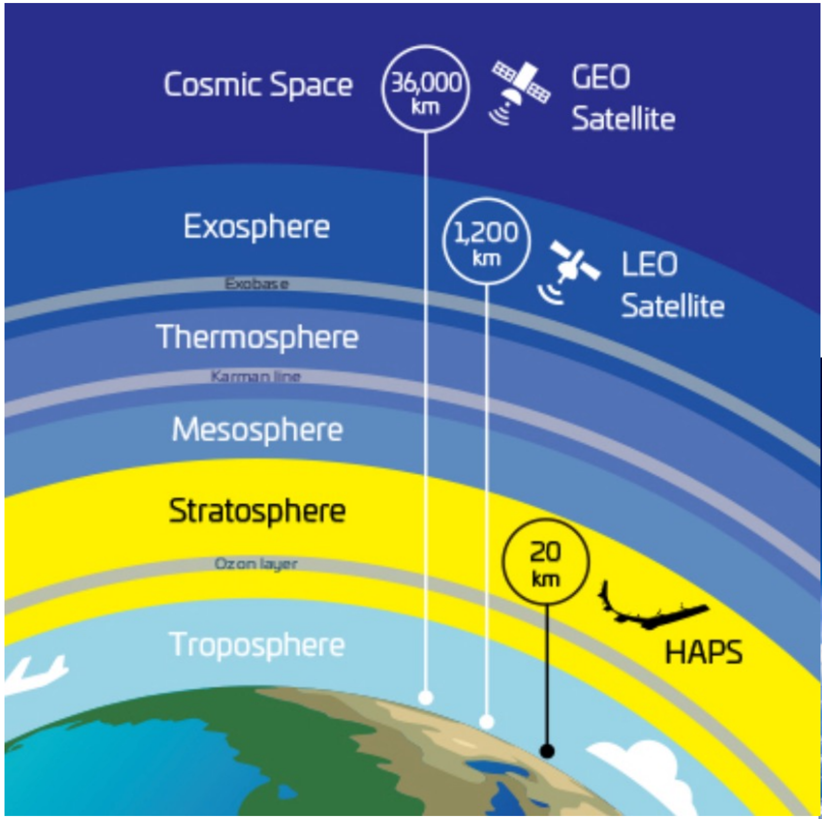
無線を介した遠隔手術の問題点



通信分野での発展性

無線通信の将来性



RTT
GEO: 200 msec
LEO: 9 msec
HAPS: 0.3 msec

HAPS Mobile社のHPより転載

NTT Homepage 2022/4/26 ニュースリリースより


5G
5G
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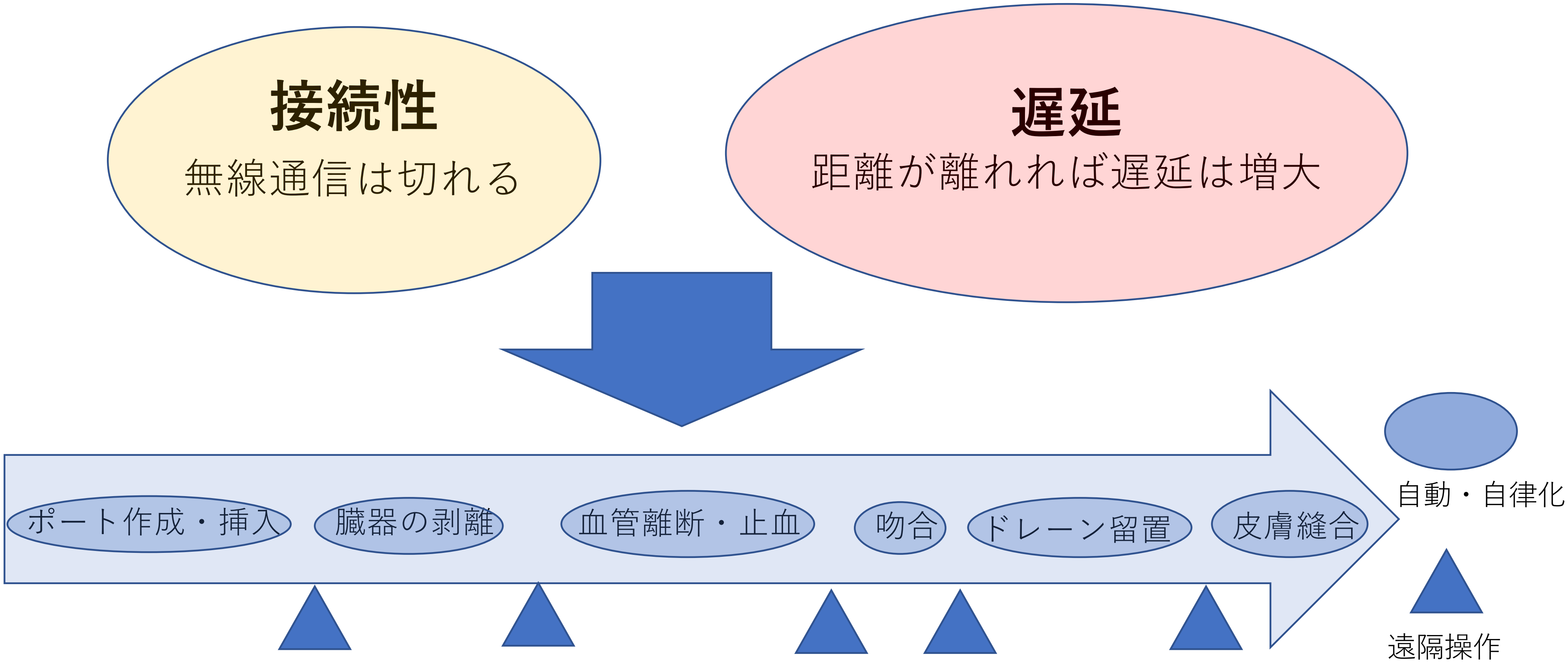
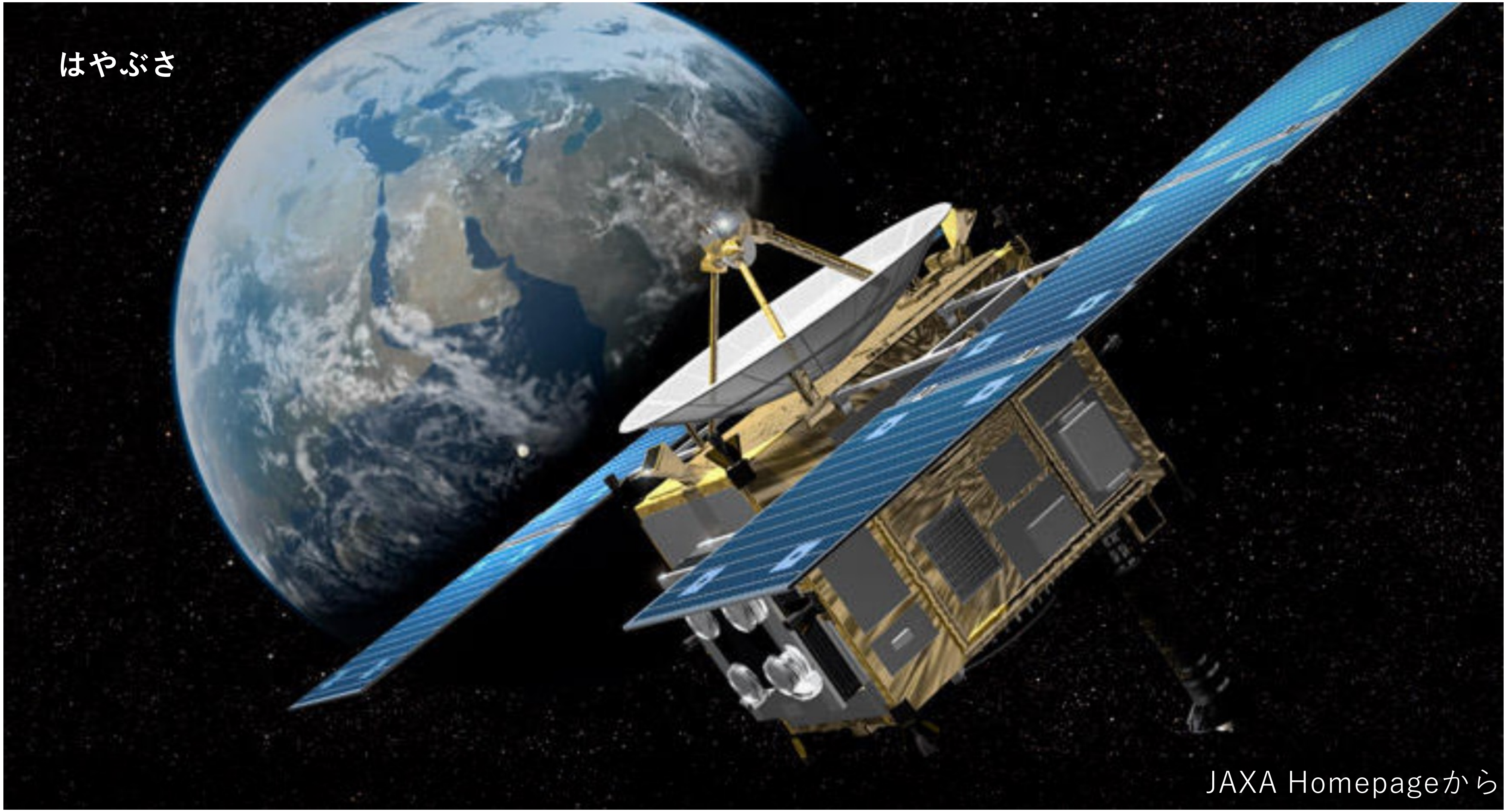
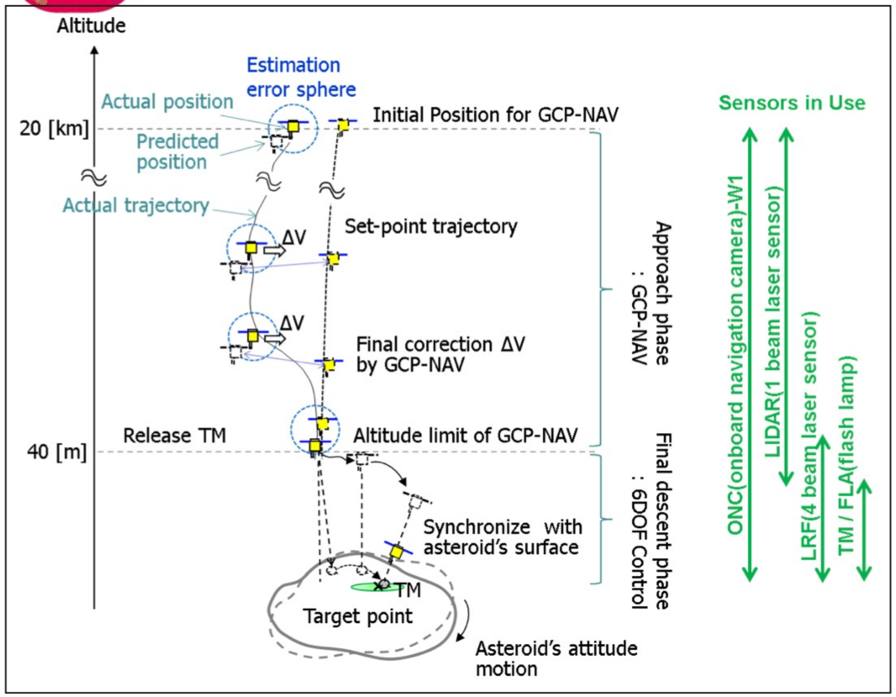
ロボット分野での発展性

無線を介した遠隔手術の問題点




はやぶさ
JAXA Homepageから

JAXAのはやぶさ遠隔操作の技術を遠隔ロボット手術へ



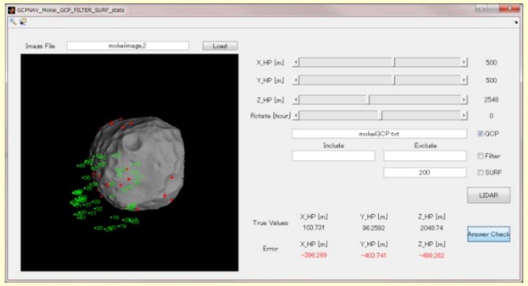
- <u>Ground Control Point Navigation（GCP-NAV）</u>

✓ 20km～数100mまでの接近時に使用する遠隔操作航法。

✓ 小惑星画像を地上に伝送。小惑星の特徴点、輪郭線をCGﾃﾝﾌﾟﾚｰﾄ画像とのﾏｯﾁﾝｸﾞで合わせこむことにより、探査機と小惑星の位置・姿勢情報を検出。

✓ これをもとに、ｴﾝｼﾞﾝの噴射量を地上で計算し探査機に指令を出す。

✓ 複雑な画像の認識、全体状況の瞬時判断は人間が得意。通信時間遅れがあっても地上指示が有利。



<u>GCP-NAV運用画面例</u>

- <u>Guidance Sequence Program (GSP)</u>

✓ センサ情報に基づき、探査機が自律的に行う振る舞いのパタンを、地上から効率的に書換え教示できるしくみ。

✓ 小惑星の表面状態さ光の反射度等、近傍観察し初めて得られる情報を把握した後、危険判断の基準、危険時の対応等を地上運用者が分析の上決定し、自律動作を開始する前に、地上指令として探査機内のテーブルを書き換える。

✓ 通信容量や探査機の計算機メモリの制約から効率的書換え・教示の仕組みが重要。

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BJU Int 2019; **124:** 487–495
wileyonlinelibrary.com

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A deep-learning model using automated performance metrics and clinical features to predict urinary continence recovery after robot-assisted radical prostatectomy

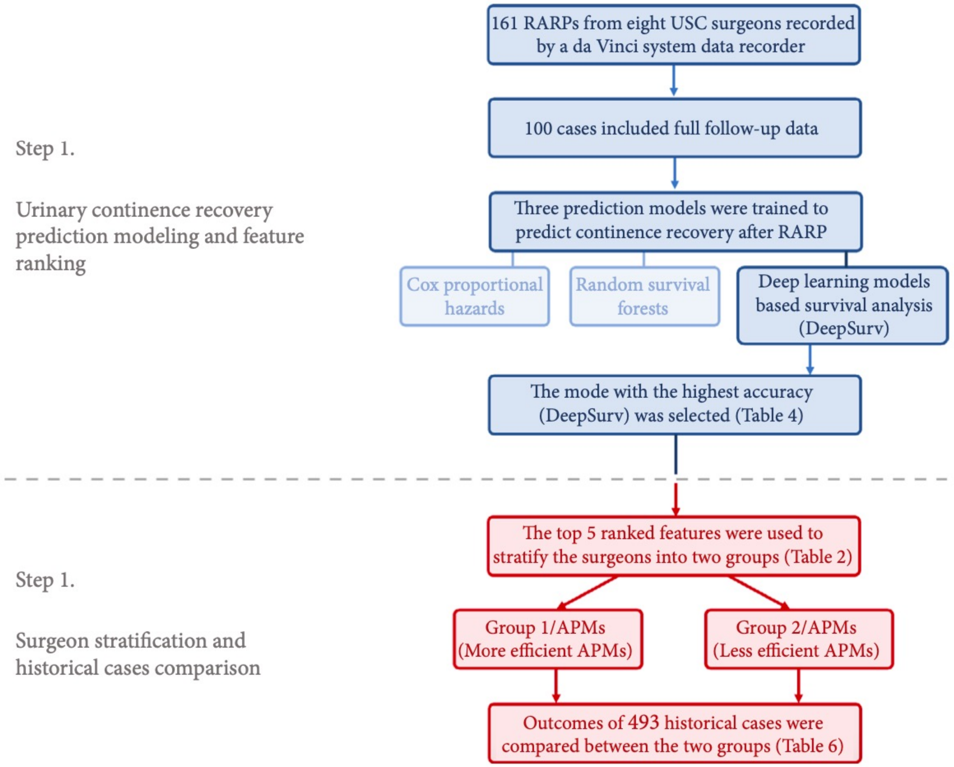
Andrew J. Hung*, Jian Chen*, Saum Ghodoussipour*, Paul J. Oh*, Zequn Liu†, Jessica Nguyen*, Sanjay Purushotham‡, Inderbir S. Gill* and Yan Liu§

*Center for Robotic Simulation and Education, USC Institute of Urology, Keck School of Medicine, University of Southern California, Los Angeles, CA, USA, †School of Electronics Engineering and Computer Science, Peking University, Beijing, China, ‡Department of Information Systems, University of Maryland, Baltimore, MD, and §Computer Science Department, Viterbi School of Engineering, University of Southern California, Los Angeles, CA, USA

Table 1 Automated performance metrics and patient clinicopathological features.

APM	Frequency of master clutch usage
Time-related metrics	Frequency of third arm swap
Time to complete the task	Frequency of energy application
Moving time of the right instrument	Number of times surgeon's head out of the console
Moving time of the left instrument	EndoWrist® articulation metrics
Moving time of third instrument	The total radians of the right instrument shaft rotation during the task
Moving time of the camera	The total radians of the right instrument wrist movement during the task
Time of no instrument or camera movement	The total radians of the right instrument jaw opening during the task
Time of the right instrument not moving during the task	The total radians of the left instrument shaft rotation during the task
Time of the left instrument not moving during the task	The total radians of the left instrument wrist movement during the task
Time of the third instrument not moving during the task	The total radians of the left instrument jaw opening during the task
Time of the camera not moving during the task	Right instrument articulation during the task
Instrument kinematic metrics	Left instrument articulation during the task
Path length of the right instrument	Angular velocity of the right instrument articulation
Moving velocity of the right instrument	Angular velocity of the left instrument articulation
Path length of the left instrument	**Clinicopathological features**
Moving velocity of left instrument	Age
Path length of the third instrument	BMI
Path length of all three instruments	Preoperative PSA
Ratio of path length of right and left instruments	Preoperative biopsy Gleason score
Camera movement metrics	ASA
Path length of the camera	Surgery time
Moving velocity of the camera	Lymph node dissection template (standard vs extended)
Number of camera adjustments during the task	Urethropexy
Frequency of camera adjustment	Nerve-sparing
Mean of time of each camera movement	Prostatic median lobe
Mean path length of each camera movement	Final pathology Gleason score
Mean of straight path length of each camera movement	Pathological stage
System event metrics	Extracapsular extension
Master clutch usage during task	Prostate volume
Third arm swap during task	Positive margins
Energy usage during task	Radiation received

APM, automated performance metric; ASA, American Society of Anesthesiologists; BMI, body mass index.



Objectives

To predict urinary continence recovery after robot-assisted radical prostatectomy (RARP) using a deep learning (DL) model, which was then used to evaluate surgeon's historical patient outcomes.

Subjects and Methods

Robotic surgical automated performance metrics (APMs) during RARP, and patient clinicopathological and continence data were captured prospectively from 100 contemporary RARPs. We used a DL model (DeepSurv) to predict postoperative urinary continence. Model features were ranked based on their importance in prediction. We stratified eight surgeons based on the five top-ranked features. The top four surgeons were categorized in 'Group 1/APMs', while the remaining four were categorized in 'Group 2/APMs'. A separate historical cohort of RARPs (January 2015 to August 2016) performed by these two surgeon groups was then used for comparison. Concordance index (C-index) and mean absolute error (MAE) were used to measure the model's prediction performance. Outcomes of historical cases were compared using the Kruskal–Wallis, chi-squared and Fisher's exact tests.

Results

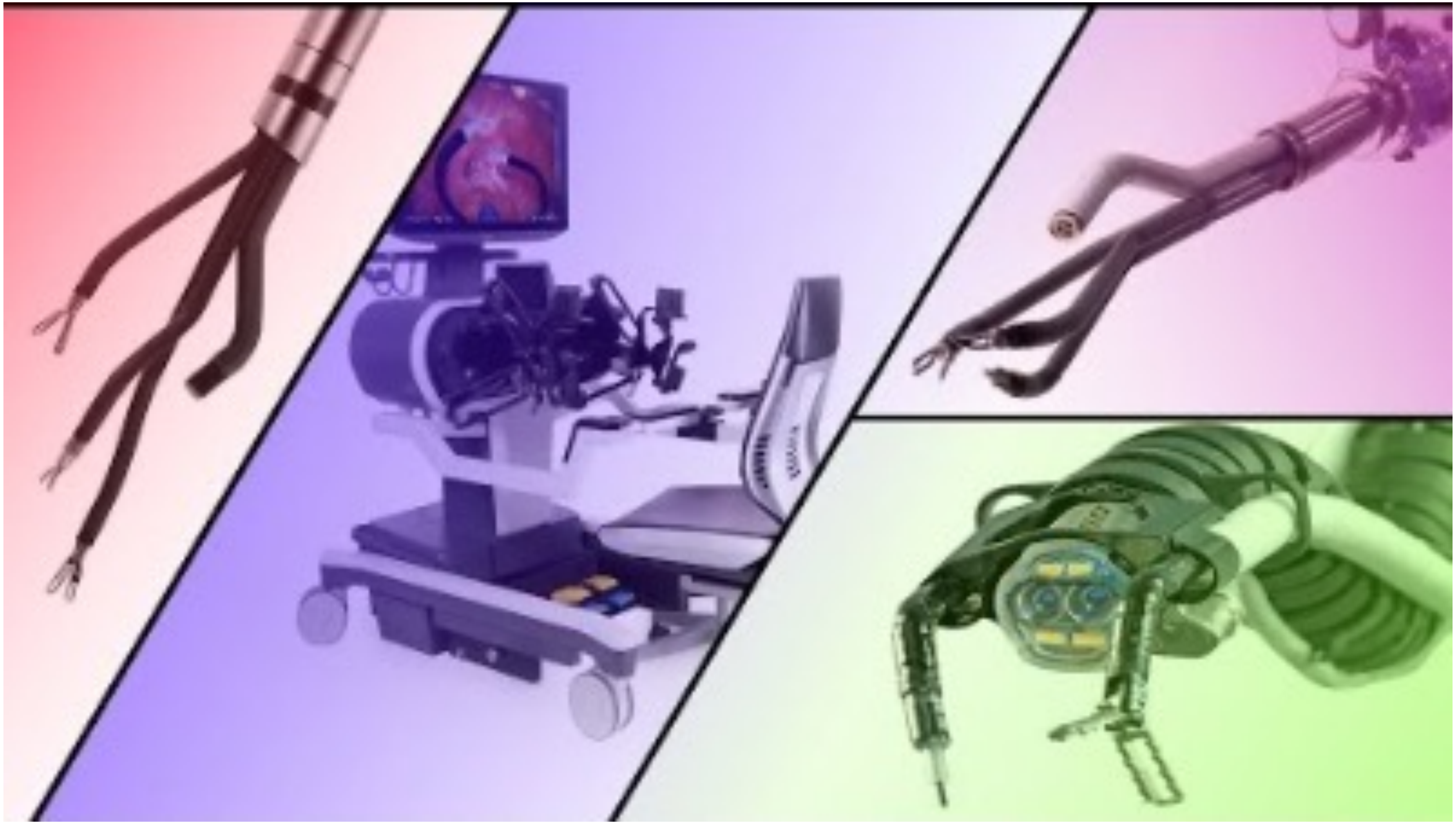
Continence was attained in 79 patients (79%) after a median of 126 days. The DL model achieved a C-index of 0.6 and an MAE of 85.9 in predicting continence. APMs were ranked higher by the model than clinicopathological features. In the historical cohort, patients in Group 1/APMs had superior rates of urinary continence at 3 and 6 months postoperatively (47.5 vs 36.7%, $P = 0.034$, and 68.3 vs 59.2%, $P = 0.047$, respectively).

Conclusion

Using APMs and clinicopathological data, the DeepSurv DL model was able to predict continence after RARP. In this feasibility study, surgeons with more efficient APMs achieved higher continence rates at 3 and 6 months after RARP.

Keywords

robotic surgical procedures, prostatectomy, artificial intelligence, urinary incontinence, quality of life



ご清聴ありがとうございました