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Modeling the Lifetime Impact of Reconstructive Plastic Surgery Training: Implications for Building Capacity in Global Surgery

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Background: Training local surgeons and building local surgical capacity is critical to closing the gap in unmet surgical burden in low- and middle-income country (LMIC) settings. We propose a conceptual framework to quantify the impact of a single surgeon's training across multiple generations of trainees.
Methods: A literature review was conducted to identify existing models for quantifying the impact of training. A model to estimate the attributable impact of surgical training was devised, based on a surgeon's attributable impact on a trainee and the lifetime number of cases trainees would perform. A quantitative survey was sent to high-income country and LMIC-based surgeons to determine the model's inputs across eight index procedures in reconstructive plastic surgery.
Results: We found no existing models for quantifying the multigenerational impact of training in surgery, medicine, or nonmedical fields. Twenty-eight US-based academic plastic surgeons and 19 LMIC-based surgeons representing 10 countries provided responses. The lifetime impact of multigenerational surgical training ranged from 4100 attributable cases (skin graft) to 51,900 attributable cases (cleft lip repair) in high-income countries and from 18,200 attributable cases (carpal tunnel release) to 134,300 attributable cases (cleft lip repair) in LMICs.
Conclusions: There is a sizeable impact in the first generation of training, and this impact is even greater in the second generation of training, highlighting the importance of a "multiplier effect," particularly in LMIC settings. Given the paucity of surgeons, this multiplier effect is critical in closing the surgical gap, as efforts are underway to train new cohorts of reconstructive plastic surgeons. *(Plast Reconstr Surg Glob Open 2024; 12:e5577; doi: 10.1097/GOX.0000000000005577; Published online 5 February 2024.)*

INTRODUCTION

In the past several decades, global health has experienced an epidemiological shift in the burden of noncommunicable diseases (NCDs).[1–3] Injuries represent a significant portion of the NCD burden, with mortality double that of infectious diseases or malnutrition.[4] As such, there has been a concomitant growing recognition of the role of surgery as a means to address unmet needs in global health.[5,6] In 2015, the Lancet Commission on Global Surgery found that 5 billion people lack access to safe surgical care and that an additional 143 million surgical procedures are needed in low- and middle-income countries (LMICs) each year to relieve the unmet burden.[7] This commission also recognized that surgical services in LMICs were both affordable and feasible, and that "urgent investment in human and physical resources for surgical and anesthesia care is needed."

Historically, global surgery efforts in LMICs have focused on the surgical mission model of bringing teams of surgeons, anesthesiologists, nurses, and other healthcare professionals to local hospitals and performing high volumes of cases in a relatively short time. Although cost-effective, they do not address the underlying challenge of inadequate local surgical capacity.[8–10] There is a profound shortage of surgeons in LMICs, and the need for more surgical training is immense. While general surgery capacity in LMICs has started to increase in recent years, reconstructive plastic surgery has sorely lagged behind.[11] In 2014, the entire country of Uganda had only three plastic

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surgeons for a population of 36 million people (one surgeon per 12 million people)[12]; Zambia (population 15 million people) had just one.[13] In sharp contrast, the United States has 12,000 plastic surgeons for a population of 330 million people (one surgeon per 0.027 million people).

In recent years, there is a growing recognition of the importance of training surgeons in LMIC settings and building local surgical capacity.[7,14–16] Inherent to surgical training is the linear transmission of knowledge through hands-on teaching and experience. Trainees who receive surgical training while in residency and fellowship will later pass on that knowledge to future generations of new trainees. However, quantifying the extent and impact of surgical training has been a challenging problem, given the tremendous variation in surgical training programs across the world.

Given the wide disparities in healthcare between high-income countries (HICs) and LMICs, it is necessary to understand the extent to which training a single new surgeon can relieve the future burden of surgical disease in a community. To that end, we seek to characterize the number and duration of trainer-trainee teaching relationships of plastic surgeons in HIC and LMIC settings and to propose a conceptual framework to estimate the attributable impact of a single surgeon's training across multiple generations of trainees.

Takeaways

Question: What is the lifetime impact of a single surgeon training multiple generations of trainees?

Findings: In eight index reconstructive plastic surgery procedures, one surgeon can have an attributable impact of tens of thousands of cases for each procedure. This impact is often substantially larger in the second generation of trainees.

Meaning: There is a critical "multiplier effect" that amplifies the impact of a surgeon's training across generations. This multiplier effect is critical in closing the surgical gap, particularly in low- and middle-income countries.

METHODS

A model for lifetime impact of a single surgeon's training across multiple generation of trainees was developed in three steps: literature review and qualitative survey to identify existing models, model generation, and quantitative survey for model scaling factors.

Existing Models

Literature searches were conducted in the PubMed and ScienceDirect databases using the keywords "surgery," "training," "impact," "knowledge," "longitudinal," and "generation" to identify existing studies that (1) measure the impact of surgical training and (2) propose models to quantify the transmission of surgical knowledge across multiple generations. Additionally, an exploratory literature review was conducted in the teaching and education literature (not limited to surgery or medicine) regarding the impact of multigenerational training. After failing to identify suitable models in the literature, a qualitative survey was created to solicit expert opinion from established trainers in nonsurgical fields. Field experts were chosen in fields in which hands-on training and experience are necessary. The qualitative survey assessed metrics used to measure proficiency, methods of gaining knowledge and proficiency, number and duration of typical trainer-trainee relationships, and the perceived persistence of knowledge over time.

Model Generation

The impact of a surgeon's training was defined as the number of lifetime cases that would be attributed to that surgeon over two successive "generations" of trainees. As a conservative boundary, the definition of "multigenerational" was limited to two generations, beyond which it would be difficult to accurately attribute individual training and impact. For a hypothetical surgeon A, the framework for two generations of trainees is defined as follows. In generation 1, surgeon A trains resident B and resident C. In generation 2, residents B and C complete training and become attending surgeons (new trainers); attending B trains residents D and E, whereas attending C does not train any residents. The attributable impact of surgeon A is therefore defined as the number of lifetime cases performed by surgeons B, C, D, and E. Given that trainees may have multiple trainers from whom they learn a procedure (eg, a resident will learn carpal tunnel release techniques from several attending surgeons), a scaling factor was added to account for this effect.

Quantitative Survey

A survey was created to estimate the scaling factor for each reconstructive procedure. A panel of two physicians and one global health expert evaluated what factors may theoretically modify the life-time impact of training and, through consensus opinion, created a series of survey questions to derive those factors. The survey was designed to estimate the training impact for a single surgeon, based on the surgeon's average number of lifetime trainees and number of lifetime cases in certain index procedures. Index procedures were selected to encompass a range of plastic surgery subspecialities that would be performed in both HICs and LMICs. Surveys were distributed to board-certified US plastic surgeons based in academic medical institutions and plastic surgeons practicing in local hospitals in LMIC settings.

RESULTS

Existing Models

Literature review initially identified 48 studies that evaluated the impact of surgical training. However, upon further review, all studies either (1) focused on a specific training technique (eg, impact of robotic simulators for laparoscopic surgery), (2) centered around a specific change to surgical training (eg, impact of implementation of duty work-hours restrictions), or (3) evaluated impact based on patient experience rather than surgeon experience (eg, quality-of-life improvements following colorectal surgery). As such, none of the studies that were identified provided a suitable framework for evaluating the longitudinal impact of surgical training.

A qualitative survey to explore models of quantifying the impact of training in nonsurgical fields was sent to 20 participants; the survey response rate was 75%. Participants were chosen to represent professions in which hands-on (in contrast to purely didactic) training and experience are a necessary part of knowledge transmission. Respondents represented the following fields:

- Military – US Navy (retired vice admiral), US Army (warrant officer)
- Law: corporate law (professor), criminal law (solicitor)
- Physical sciences: chemistry (professor), biology (professor)
- Medicine: internal medicine (professor), surgery (division chief)
- Technology: operations (chief of staff)
- Humanities: English (professor)
- Arts: music (singer), fashion (tailor)
- Design: product design (professor)
- Public safety: police (chief), fire protection (engineer)

All respondents reported that their respective fields did not have a method of quantifying the impact of training or of measuring the extent to which training passes through multiple generations of trainees. One respondent noted: "In [US Navy] aviation training, we have a formalized channel, training methodology, and set of venues for passing those important emergent new skills to subsequent generations of pilots, but we do not have a way to measure the attributable impact of those channels."

Model Generation

We proposed a model to quantify the attributable impact of surgical training from a single surgeon over two generations of trainees. In theory, the attributable impact of a single trainer could be extended ad infinitum. From a practical standpoint though, the attributable impact becomes diluted in each successive generation.

The framework to quantify attributable surgical impact was with respect to two terms: individual impact factor (IIF) and the lifetime number of cases that one surgeon's trainees are estimated to perform (Fig. 1).

- IIF was defined as 1/(Number of surgeons teaching a procedure). For example, if four surgeons at an institution teach carpal tunnel release to trainees, then ¼ of the trainee's lifetime cases would be attributable to each trainer surgeon.
- Lifetime number of cases was defined as (years in practice as a trainer) × (number of trainees per year) × (years in trainee's practice) × (number of trainee cases per year), based on the following assumptions:
  - The final "unit of impact" being measured is the number of procedures that are performed by surgeons who were taught how to perform those procedures by the original trainer. This provides an estimate of the transmission of surgical training from the original trainer to a lifetime of trainee cohorts who now perform those procedures independently.
  - Number of trainee cases per year provides the annual case volume of a specific procedure for a single surgeon who learned the procedure from the original trainer and is now practicing independently. This value multiplied by years in trainee's practice, therefore, provides the lifetime case volume of a specific procedure for that single surgeon who learned the procedure from the original trainer.
  - Number of trainees per year provides the annual number of graduating residents and fellows to whom the surgeon teaches the relevant procedure and is expected to perform that procedure in their own practice. For instance, not all trainees who are taught how to perform cleft lip repairs may actually do so in their own practice. This value multiplied by years in practice as a trainer provides the lifetime number of graduating residents and fellows to whom the surgeon teaches the relevant procedure.

Additionally, the attributable impact from generation 2 also includes an adjustment factor for surgeons who ultimately practice in settings that do not interact with residents (eg, resident C becomes an attending and does not train any residents in his or her career.) In these instances, the surgical knowledge of surgeon A is not passed on further through surgeon C. To estimate this attrition factor, we reviewed the last 20 years of graduates from a single plastic surgery residency program. Based on this review, the attrition factor was estimated to be ½. Thus, in generation 2, the ASI is defined as IIF x lifetime trainee cases x ½.

Quantitative Survey

A quantitative survey was sent to surgeons in HIC and LMIC settings to estimate the scaling factors for the surgical impact model. All surgeons estimated the number of years they expected to be in practice and the

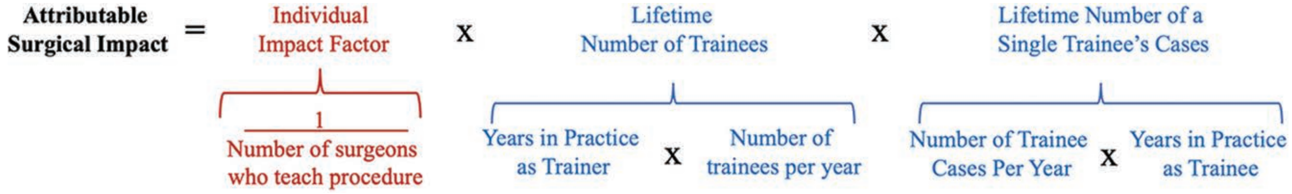

Fig. 1. Framework used to calculate the lifetime impact of a single surgeon's teaching.

number of trainees graduating from their hospital annually. Additionally, surgeons were asked to describe their practice patterns for eight index cases: cleft lip repair, facial reconstruction with local flap, wound coverage with skin graft, wound coverage with free flap, pressure sore coverage, breast reduction, carpal tunnel release, and syndactyly repair. For each index case, surgeons estimated annual number of cases performed, number of trainers who taught them the procedure, and number of trainees who were expected to perform the procedure in the future.

Surveys were returned from 28 plastic surgeons in US-based surgical training programs and 19 plastic surgeons in LMIC settings. US-based surgeons reflected training at small (one graduating resident per year), medium (two-three graduating residents per year), and large (four or more graduating residents per year) programs. LMIC surgeons represented training programs in Ecuador, Ethiopia, India, Kenya, Mozambique, Nepal, Rwanda, Uganda, Zambia, and Zimbabwe. The size of LMIC programs ranged from one to five graduating residents per year (median: two residents per year).

In HICs, the lifetime impact of surgical training by a single trainer ranged from 4100 attributable cases (skin graft; 2900 in generation 1 and 1200 in generation 2) to 51,900 attributable cases (cleft lip repair; 12,900 in generation 1 and 39,000 in generation 2). In LMICs, the lifetime impact of surgical training by a single trainer ranged from 18,200 attributable cases (carpal tunnel release; 4600 in generation 1 and 13,600 in generation 2) to 134,300 attributable cases (cleft lip repair; 27,900 in generation 1 and 95,300 in generation 2). See Tables 1 and 2 and Figure 2 for full data.

DISCUSSION

The burden of surgical disease in LMICs is immense. Even when surgical access is available, the services can be cost-prohibitive; an estimated 33 million individuals face "catastrophic health expenditure due to payment for surgery and anesthesia care" every year.[7] Concerns of postoperative complications may lead patients to avoid seeking care even when that care is subsidized or free.[17] The implementation of the WHO Surgical Safety Checklist has been shown to reduce complications in surgical settings around the world and may encourage more patients to seek care.[18] Task-shifting has also been used to off-load work from overburdened healthcare.[19] However, there is no task-shifting equivalent for a trained surgeon in the operating room. Ultimately, at the root of all of these issues is a shortage of trained surgeons.

In this study, we examined the impact that a single surgeon creates through a lifetime of training residents who in turn train another generation of surgeons. There is a sizeable impact in the first generation of training, and furthermore, in nearly all instances, the impact is amplified several-fold in the second generation of training. It is the repetition and propagation of training that creates a "multiplier effect," which leads to long-term sustainability

Table 1. Trainer/Trainee Relationships, Surgical Volumes, and Multigenerational Training Impact for Eight Surveyed Index Cases in HIC Surgical Training Programs

	Co-surgeons Teaching Procedure (#)	Trainees Performing Procedure (#)	Cases Performed per Year (#)	Generation 1 Attributable Impact (# Cases)	Generation 2 Attributable Impact (# Cases)
Pressure sore	4.1	2.3	8.4	2850	6650
Skin graft	21.7	3.2	22.5	2900	1100
Syndactyly	5.6	2.6	6.0	2650	5200
Wound reconstruction with free flap	8.7	1.6	15.6	5400	6900
Facial reconstruction with local flap	5.9	3.6	16.7	7450	12,200
Breast reduction	6.1	2.4	26.9	8550	12,200
Carpal tunnel release	13.7	2.2	40.5	13,100	6600
Cleft lip	4.4	2.0	18.2	10,100	27,900

Table 2. Trainer/Trainee Relationships, Surgical Volumes, and Multigenerational Training Impact for Eight Surveyed Index Cases in LMIC Surgical Training Programs

	Co-surgeons Teaching Procedure (#)	Trainees Performing Procedure (#)	Cases Performed per Year (#)	Generation 1 Attributable Impact (# Cases)	Generation 2 Attributable Impact (# Cases)
Pressure sore	3.7	2.0	8.5	10,400	34,900
Skin graft	8.6	2.8	54.5	19,000	25,600
Syndactyly	3.6	2.6	20.2	13,500	44,500
Wound reconstruction with free flap	3.7	1.9	8.5	8300	39,400
Facial reconstruction with local flap	3.4	2.3	16.7	12,000	41,600
Breast reduction	2.4	1.3	6.6	3500	16,900
Carpal tunnel release	3.7	2.0	8.5	4600	13,600
Cleft lip	4.8	2.4	73.2	39,000	95,300

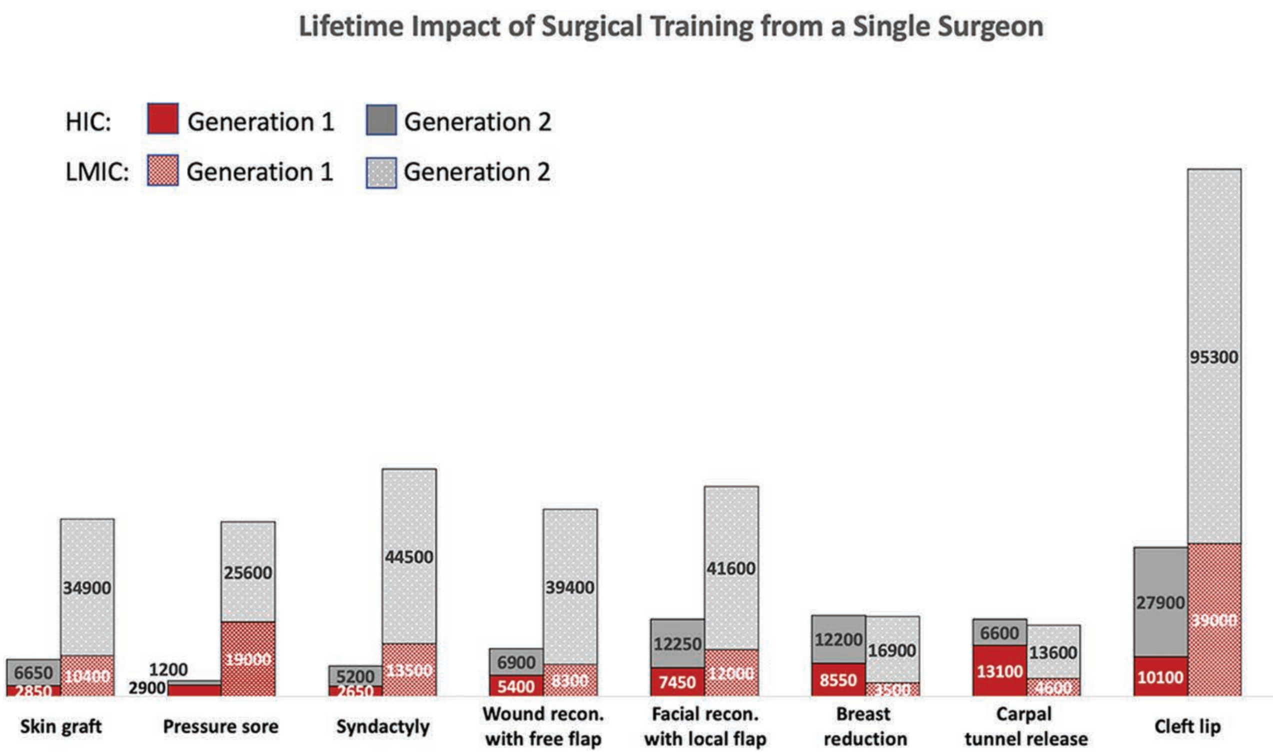

Fig. 2. Lifetime attributable impact of surgical training from a single surgeon in eight index procedures in reconstructive plastic surgery, as evaluated in HIC and LMIC settings.

and ensures more equitable healthcare access around the world. We did not include the full range of procedures that a single plastic surgeon may perform, yet even with this limited scope, the multiplier effect of training is evident.

Additionally, these findings highlight the need for a longitudinal perspective on expanding surgical access. Surgical mission trips have an immediately apparent impact that can be measured by number of patients seen or procedures completed, but the impact of these metrics do not scale beyond the individual patient. In contrast, it takes several years of investment to train a surgeon, and only after that time does a surgeon enter the pool of trainers. Once a surgeon becomes a trainer, it takes still more years until their trainees are able to perform cases independently and train a subsequent generation of trainees. These findings reflect the impact of training over decades, and once it is fully realized, this impact is immense.

For a majority of the index cases examined, the lifetime impact of surgical training was significantly greater for surgeons in LMICs than in HICs. A single surgeon teaching facial reconstruction with local flaps in LMIC settings would yield a 2.7-fold increase in attributable lifetime cases when compared with a teaching surgeon in an HIC setting. For a basic procedure, such as skin grafting, the attributable impact in LMIC settings is even more impressive, with a 10-fold increase in lifetime cases.

The two index cases for which this trend did not hold were breast reduction and carpal tunnel release. For breast reduction, LMIC surgeons reported performing an average of only seven cases per year, whereas HIC surgeons reported performing an average of 29 cases per year. This discrepancy was even starker in carpal tunnel release, in which LMIC surgeons reported performing an average of nine cases per year, whereas HIC surgeons reported performing 68 cases per year. These findings are likely due to the semielective nature of these two procedures. Given the low number of surgeons in LMICs settings, much of their operating capacity must be committed to nonelective procedures. However, the quality-of-life improvements from these two procedures have been well described and are a core part of the plastic surgeon's armamentarium. By increasing surgical capacity and closing the surgical gap in emergency cases, less-urgent procedures will eventually become a priority as well.

It is worth noting that there are significant differences in training programs between HIC and LMIC programs. For four of the LMIC-based surgeons that were surveyed, their hospital represents the only reconstructive plastic surgery training program in the country, and as such, there is a greater concentration of knowledge with respect to training and transmission of knowledge. This is in large part due to the extremely limited number of plastic surgeons in those countries, and as a result, the number of facilities capable of teaching future generation of surgeons.

This study does have limitations that warrant discussion. The survey respondents in this study were all based in either academic medical centers in HICs or large hospital practices in LMICs, and as such, the findings may not be applicable to all hospitals. Additionally, given that a given hospital may specialize in a different type of surgery, and therefore attract different kinds of patient needs, it may be difficult to generalize findings across all hospitals. However, given that surgical training programs are by-and-large based in academic healthcare centers, we believe that these results broadly reflect the surgical training landscape. Additionally, these findings were based on surgeons' recall of annual case volume and expectations of future trainee case volume. As such, surgeons may underestimate or overestimate their volume of cases, so true case volume may not be exact. Lastly, the IIF assumes that a trainee will use all of the training they received for a given procedure but does not account for differences in training versus practice patterns. Given that there are several ways to perform any index procedure, we have simplified our model to focus on the broad type of procedure, rather than the specifics of how a given procedure is performed.

The burden of unmet need for surgical diseases in LMICs is tremendous. The impact of training surgeons, particularly in under-resourced settings, is multi-tiered. These surgeons perform critical procedures that directly improve the lives of patients. Furthermore, these surgeons also train the next generation of local surgeons, who in turn train yet another generation of surgeons. The power of this multigenerational multiplier effect is tremendous, as a single surgeon in an LMIC setting can have a lifetime impact of over 400,000 cases through their training alone. As such, building surgical capacity through local training programs must be a part of any long-term global health initiative that seeks to close the unmet burden of surgical disease. It is our hope that these data will provide a rationale to donors and institutions to focus on increasing surgical capacity through investment in long-term training.

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DISCLOSURES

James Chang is a Consulting Medical Officer for ReSurge International. Natalie Meyers is Chief Programs Officer for ReSurge International. Lawrence Cai has no financial interest to declare in relation to the content of this article.

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